Technology Collaboration Programme
by iea

International Energy Agency
Photovoltaic Power Systems Programme

Task 1 Strategic PV Analysis and Outreach

PVPS

TRENDS IN PHOTOVOLTAIC APPLICATIONS 2025

REPORT IEA PVPS T1-48:2025

PHOTOVOLTAIC POWER SYSTEMS TECHNOLOGY COLLABORATION PROGRAMME

WHAT IS IEA PVPS TCP?

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The Technology Collaboration Programme (TCP) was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of thousands of experts across government, academia, and industry dedicated to advancing common research and the application of specific energy technologies.

The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the TCP's within the IEA and was established in 1993. The mission of the programme is to "enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems." In order to achieve this, the Programme's participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct 'Tasks,' that may be research projects or activity areas. This report has been prepared under Task 1, which deals with market and industry analysis, strategic research and facilitates the exchange and dissemination of information arising from the overall IEA PVPS Programme.

The IEA PVPS participating countries in 2025 are 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, Türkiye, the United Kingdom and the USA. The European Commission, Solar Power Europe, the Solar Energy Research Institute of Singapore are also members.

Visit us at: www.iea-pvps.org

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DISCLAIMER

Front cover: Blue Sea Photovoltaic Power Station in China. Credit: Longi

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REPORT SCOPE AND OBJECTIVES

The Trends report's objective is to present and interpret developments in the PV power systems market and the evolving applications for these products within this market. These trends are analysed in the context of the business, policy and nontechnical environment in the reporting countries.

This report is prepared to assist those who are responsible for developing the strategies of businesses and public authorities, and to support the development of medium-term plans for electricity utilities and other providers of energy services. It also provides guidance to government officials responsible for setting energy policy and preparing national energy plans. The scope of the report is limited to PV applications with a rated power of 40 W or more. National data supplied are as accurate as possible at the time of publication. Data accuracy on production levels and system prices varies, depending on the willingness of the relevant national PV industry to provide data. This report presents the results of the 30th international survey. It provides an overview of PV power systems applications, markets and production in the reporting countries and elsewhere at the end of 2024 and analyses trends in the implementation of PV power systems between 1992 and 2024. Key data for this publication were drawn mostly from national survey reports and information summaries, which were supplied by representatives from each of the reporting countries. Information from the countries outside IEA PVPS are drawn from a variety of sources and, while every attempt is made to ensure their accuracy, the validity of some of these data cannot be assured with the same level of confidence as for IEA PVPS member countries.

ACKNOWLEDGMENT

This report has been prepared under the supervision by Task 1 participants. A special thanks to all of them.

FOREWORD

The installation of new capacity broke records again in 2024, enabling the energy transition, whilst bringing structural change in the industry. Annual installations reached the remarkable value of 601 GW (up from 465 GW in 2023), bringing the cumulative global PV capacity to over 2.2 TW at the beginning of 2025. This cumulative capacity should be able to supply at least 10% of the world's electricity consumption in 2025, generating more than an expected 2 950 TWh, avoiding just over 1 000 Mt of CO_2 emissions, equivalent to 2.8% of all energy-related emissions.

As in previous years, the Chinese PV market dominated, installing close to 360 GW alone - around 60% of the world market. Other regions also accelerated: Europe reached an annual record of 70 GW, the USA added 47 GW, India rebounded to 32 GW, and Brazil confirmed its global role with 14 GW.

The sector continued to expand in parallel with economic turbulence. Extreme module overcapacities starting in 2023 translated into unsustainably low prices that threatened the viability of manufacturers across all regions. In 2024 signs of price stabilization began to appear towards the end of the year as concerted efforts were made to work on manufacturers' sustainability.

The rapid deployment of PV also highlighted system and market challenges, as record levels of curtailment were experienced around the world, underlining the urgency of grid reinforcement, storage deployment and demand-side flexibility. At the same time, diversification advanced: new volumes of agrivoltaics, floating PV, and PV+storage systems were commissioned. Large-scale PV-based hydrogen/ammonium projects continue to advance in planning stages, marking the first steps of industrial decarbonisation powered by solar.

2024 also confirmed the growing socio-economic footprint of PV. Global employment rose to around 9.1 million jobs, up from 7.2 million in 2023, with strong growth in installation, operations and maintenance, a consequence of market growth, especially in countries with higher labour intensity. PV projects are increasingly engaging First Nations communities, particularly in Canada, Australia and the USA, where new models of partnership, land rights recognition and benefit-sharing are being established as part of a more inclusive energy transition.

The achievements of 2024 show PV advancing from competitiveness to systemic importance. While industrial turbulence and integration challenges remain, PV has established itself as the fastest-growing and most competitive energy technology. Reaching the milestone of supplying more than one-tenth of the world's electricity confirms that PV is not only central to energy transition strategies but is already reshaping the global energy system. The prospects for continued rapid growth remain bright even if important challenges remain to be met in the coming years.

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TRENDS IN PHOTOVOLTAIC APPLICATIONS // 2025

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME WWW.IEA-PVPS.ORG

WORLDWIDE cSi MODULE PRODUCTION

700 GW

in 2024

TOP 5 PV MARKETS IN 2024

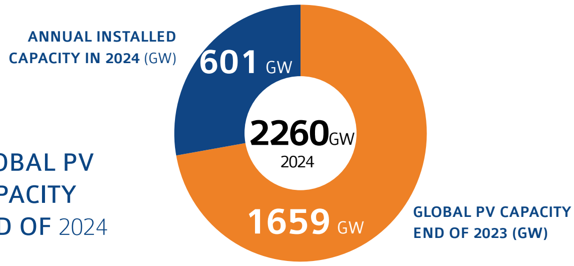
CHINA	357 GW
EU	66 GW
USA	47 GW
INDIA	32 GW
PAKISTAN	18 GW

PV CONTRIBUTION TO ELECTRICITY DEMAND

10.8%

Share of PV in the global electricity demand in 2024

GLOBAL PV CAPACITY END OF 2024

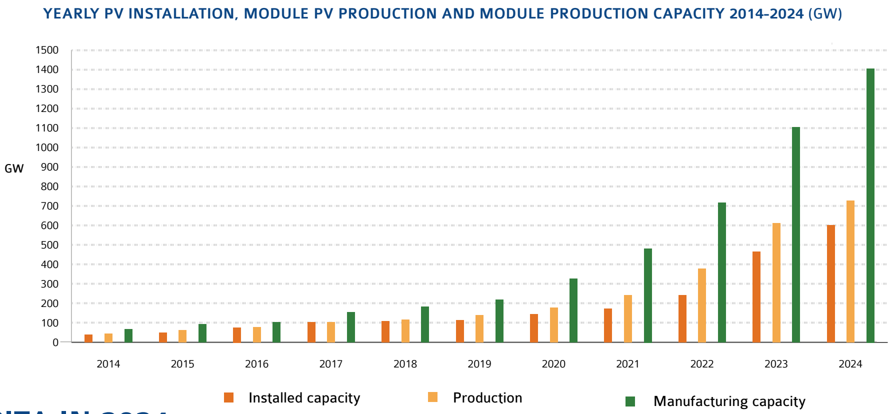


CLIMATE CHANGE IMPACTS

1 045

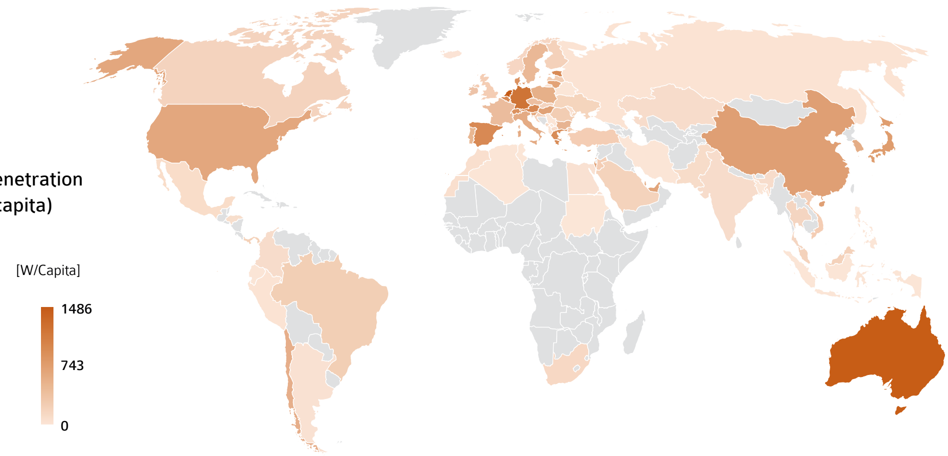
million tons of CO_2 **saved in 2024**

* method changed from 2022; now assuming PV replaces baseload generation



PV PENETRATION PER CAPITA IN 2024

PV penetration (Wp/capita)



PV POWER PER CAPITA

1. THE NETHERLANDS (1 486 Wp/CAP)
2. AUSTRALIA (1 463 Wp/CAP)
3. GERMANY (1 203 Wp/CAP)
4. BELGIUM (982 Wp/CAP)
5. AUSTRIA (970 Wp/CAP)

40 COUNTRIES REACHED AT LEAST **4 GWp** IN 2024

34 COUNTRIES INSTALLED AT LEAST **1 GWp** IN 2024

SOURCE: IEA PVPS & OTHERS

credit: Erik Karits Pexels

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INTRODUCTION TO THE CONCEPTS AND METHODOLOGY

PV TECHNOLOGY

Photovoltaic (PV) devices convert light directly into electricity and should not be confused with other solar technologies such as concentrated solar power (CSP) or solar thermal for heating and cooling. The key components of a PV power system are various types of photovoltaic cells (often called solar cells) interconnected and encapsulated to form a photovoltaic module (the commercial product), the mounting structure for the module or array, the inverter (one or multiple, essential for grid-connected systems and required for most off-grid systems) the cabling to connect the modules with each other and with the inverter(s), the storage battery and charge controller (for off-grid systems but also increasingly for grid-connected ones).

CELLS, MODULES AND SYSTEMS

Photovoltaic cells represent the smallest unit in a photovoltaic power producing device. Wafer sizes, and thus cell sizes, have progressively increased, as this is considered by industrial actors to be an easy way to improve cell and module wattage. In 2023 and 2024, major manufacturers came to a consensus and agreed to standardise towards rectangular cells, either the M10/182R - a cell with a short side of 182mm and a long side from 188 mm up to 210 mm – or the G12R/210R (182 mm x 210 mm) although the G12 (210 mm square) may progress in the coming years. In general, cells can be classified as wafer-based crystalline silicon (c-Si) (mono- and multi-crystalline), compound semiconductor (thin-film), or organic.

Today, c-Si technologies account for more than 98% of the overall cell production. Monocrystalline or Single crystalline PV cells, formed with wafers manufactured using a single-crystal growth method, feature commercial efficiencies between 20% and 25% (single junction). The silicon PV module market is nearly exclusively composed of these cells (approaching 100%), as they have replaced multicrystalline silicon (mc-Si) cells, also called polycrystalline. These were formed with multicrystalline wafers, manufactured by a cast solidification process. They were less efficient, with an average conversion efficiency of approximately 18% - 21% in mass production (single-junction) and although there are nearly no new modules with this technology entering the market, they are present in a large volume of already operational PV systems. Cells can be made from p-type or n-type c-Si; p-type technologies were developed on the market earlier than n-type technologies, but the higher efficiency levels and lower degradation rates of n-type have meant that manufacturing is shifting and in 2024 the share of n-type wafers rose from 30% to 70%, despite historically higher manufacturing costs.

Thin-film cells are formed by depositing extremely thin layers of photovoltaic semiconductor materials onto a backing material such as glass, stainless steel or plastic. III-V compound semiconductor PV cells are formed using materials such as Gallium Arsenide (GaAs) on Germanium (Ge) substrates and have high conversion efficiencies from 25% up to 30% (not concentrated). Due to their high cost, they are typically used in space applications. Thin-film modules used to have lower conversion efficiencies than basic crystalline silicon technologies, but this has changed in recent years. They are potentially less expensive to manufacture than crystalline cells thanks to the reduced number of manufacturing steps from raw materials to modules, and to reduced energy demand. Thin-film materials commercially used are cadmium telluride (CdTe), and copper indium-(gallium)-diselenide (CIGS and CIS).

PV TECHNOLOGY / CONTINUED

Organic thin-film PV (OPV) cells use dye or organic semiconductors as the light-harvesting active layer.

The thin-film cell technology efficiency ranges between 14% (OPV),[1] 19.2% (CIGS and CIS), 19.9% (CdTe), 25.1% single junction GaAs and 31.2% three-junction GaAs (non-concentrated) and above 35% for some CPV modules. It should be noted that cell conversion efficiencies are generally 2.5% higher than the commercial module efficiency indicated here.

Organic and inorganic hybrid materials such as perovskites are also used for photovoltaic materials. Perovskite technology has created increasing interest and research over the last few years and is currently the fastest advancing solar technology. Despite the potentially low production costs, stable products are difficult to manufacture, nevertheless development and demonstration activities are underway with pilot lines launched in Europe and China. Tandem cells based on perovskites are an important focal point of current research, with either a crystalline silicon base or a thin film base . Experimental silicon-based tandem perovskite solar cells hit 34.6% efficiency in 2024, and 30.1% for M6 standard wafers (LONGi).

Photovoltaic modules are typically rated from about 440 W to 720 W in 2024, or even up to 760W in 2025 for bifacial glass modules, depending on the technology and the size – although typical sizes for residential systems in 2024 was 435 W to 550 W, with modules above 670 W more often reserved for centralised ground mounted systems. Specialized products for building integrated PV systems (BIPV) exist, sometimes with higher nominal power due to their larger sizes. Crystalline silicon modules consist of individual PV cells connected and encapsulated between a transparent front, usually glass, and a backing material, usually plastic or glass. Thin film modules encapsulate PV cells formed into a single substrate, in a flexible or fixed module, with transparent plastic or glass as the front material.

A PV system consists of one or several PV modules, connected to either an electricity network (grid-connected PV) or to a series of loads (off-grid). It comprises various electric devices aimed at adapting the electricity output of the module(s) to the standards of the network/ grid or the load: inverters, charge controllers or batteries.

A wide range of mounting structures have been developed - especially for BIPV - including PV facades, sloped and flat roof mountings, integrated (opaque or semi-transparent) glass-glass modules and PV tiles.

Single or two-axis tracking systems are attractive for ground mounted systems, particularly for PV utilization in countries with a high share of direct irradiation. By using such systems, the energy yield can be increased from 15% to 35% for single axis and 25% to 50% for dual axis trackers compared with fixed systems. The precise gain depends not only on the latitude of the system, but also the orientation of single axis trackers and the eventual controls and algorithms used to manage the tracking system

1. Module efficiencies are reported from the NREL Champion Module Efficiencies for small or standard modules: https://www.nrel.gov/pv/module-efficiency.html

PV APPLICATIONS AND MARKET SEGMENTS

When considering distributed PV systems on buildings, it is necessary to distinguish building applied photovoltaics (BAPV) and buildings integrated photovoltaics (BIPV) systems. BAPV refers to PV systems installed on an existing building as an addition to the existing envelope while BIPV implies that the PV replaces conventional building materials such as roofing elements or facades. IEA PVPS Task 15 has reviewed several definitions and versions of how to define BIPV, and compiled it into one:

"A BIPV module is a PV module and a construction product together, designed to be a component of the building. A BIPV product is the smallest (electrically and mechanically) non-divisible photovoltaic unit in a BIPV system which retains building-related functionality. If the BIPV product is dismounted, it would have to be replaced by an appropriate construction product.

A BIPV system is a photovoltaic system in which the PV modules satisfy the definition above for BIPV products. It includes the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems needed to integrate the BIPV products into the building."

And the same definition is used in this report. Amongst BIPV solutions, PV tiles, or PV shingles, are typically small, rectangular solar panels that can be installed alongside conventional tiles or slates using a traditional racking system used for this type of building product. BIPV products can take various shapes, colours and sizes and be manufactured using various materials, although a vast majority use a glass sandwich composition. They generally replace conventional building envelope solutions, or, less often, provide elements of architectural interest.

Bifacial PV modules collect light on both sides of the panel. Depending on the reflection of the ground underneath the modules (albedo), the energy production increase is estimated to be around 15% but may reach a maximum of up to 30-35% with single axis tracking systems. Bifacial modules have a growing competitive advantage despite higher overall installation costs, and it is estimated that

PV APPLICATIONS AND MARKET SEGMENTS / CONTINUED

more than 75% of modules manufactured in 2024 were bifacial, up from approximately 50% in 2023. Some challenges remain in being able to accurately simulate the performance of bifacial modules.

Floating PV systems are mounted on a structure that floats on a water surface and can be associated with existing grid connections, for instance when in the vicinity of a hydro power dam. The development of floating PV on man-made water areas is a solution to land scarcity problems in high population density areas and presents other advantages including reduced evaporation rates in dry climates and improved cooling of PV modules for better efficiency in warm climates. Off-shore floating PV systems are installed in several places.

Agricultural PV combines crops and energy production on the same site. PV can either be a static tool added into pastures or crops or a dynamic tool to facilitate agricultural production. The sharing of light between these two types of production potentially allows a higher crop yield, depending on the climate and the selection of the crop variety and can even be mutually beneficial in some cases, as the water which evaporates from the crops can contribute to a reduction of the PV modules' operating temperature. When combined with grazing, the shade provided by modules can increase grass quality in some climates whilst livestock grazing reduces maintenance costs for the PV system.

PV thermal hybrid solar installations (PVT) combine a solar module with a solar thermal collector, converting sunlight into electricity and capturing the remaining waste heat from the PV module to produce hot water or feed heating systems. The water circulating in the modules can reduce the operating temperature of the modules, which benefits the global performances of the system.

Vehicle integrated PV (VIPV) designates the integration of solar cells into the shell of vehicles to reduce emissions in the mobility sector. Solar cell technological developments allow new models to meet both aesthetic expectations for car design and technical requirements, such as light weight and resistance to load. Vehicle applied PV (VAPV) relates to the use of PV modules on vehicles without integration.

Infrastructure Integrated PV (IIPV) is when PV is integrated into infrastructure such as noise barriers, dam walls, pavement, roads, etc. New applications are being demonstrated regularly.

Solar Home Systems (SHS) or pico PV systems combine the use of efficient lights (mostly LEDs) with charge controllers and batteries. With a small PV panel of only a few watts, essential services can be provided, such as lighting, phone charging and powering a radio or a small computer. Expandable versions of pico PV systems have entered the market and enabled starting with a small kit and adding extra loads later. They are mainly used for off-grid basic electrification, predominantly in developing countries.

GRID-CONNECTED PV SYSTEMS

In grid-connected PV systems, an inverter is used to convert electricity from direct current (DC) as produced by the PV array to alternating current (AC) that is then supplied to the electricity network. The typical weighted conversion efficiency is in the range of 95% to 99%. Most inverters incorporate a Maximum Power Point Tracker (MPPT), which continuously adjusts the load impedance to provide the maximum power from the PV array. One inverter can be used for the whole array or separate inverters may be used for each string of modules. PV modules with integrated inverters, usually referred to as "AC modules", can be directly connected to the electricity network (where approved by network operators). They offer better partial shading management and installation flexibility. Similarly, micro-inverters connected to up to four panels also exist, and despite their higher initial cost, they present some advantages where array sizes are small and maximal performance is to be achieved. "AC modules" are increasing in balcony or micro residential systems but also linear PV systems where savings can be made on cable costs when using AC modules. In some specific projects, DC to DC inverters are used as the electricity generated is injected to DC lines such as tram and railway networks.

Grid-connected distributed PV systems are installed to provide power to a grid-connected customer or directly to the electricity network - nearly always the distribution network but, for the largest utility scale systems, sometimes the transmission network. Such systems may be on, or integrated into, the customer's premises - often on the demand side of the electricity meter, on residential, commercial or industrial buildings, or simply in the built environment on motorway sound-barriers, etc. Size is not a determining feature – while a 1 MW PV system on a rooftop may be large by PV standards, this is not the case for other forms of distributed generation.

PV APPLICATIONS AND MARKET SEGMENTS / CONTINUED

Grid-connected centralized PV systems (also called utility scale systems) perform the functions of centralized power stations. The power supplied is not physically associated with an electricity customer, and whilst the system is mostly aimed at the supply of bulk energy, they are increasingly co-located with storage to perform functions on the electricity network other than simple time-of-generation energy supply. These systems are typically ground-mounted and function independently of any nearby development.

Hybrid systems combine the+ advantages of PV and diesel generation in mini grids. They allow mitigating fuel price increases, deliver operating cost reductions, and offer higher service quality than traditional single-source generation systems. Increasingly, diesel generators are being reserved for worst case situations as battery storage becomes cheaper. Combining these technologies provides a reliable and cost-effective power source in remote places such as for telecom base stations. Large-scale hybrids can be used for large cities powered today by diesel generators and have been seen, for instance in central Africa, often in combination with battery storage.

OFF-GRID PV SYSTEMS

For most off-grid systems, a storage battery is required to provide energy during low-light periods. Several battery technologies for off-grid PV systems are commonly commercialised in 2024 including different types of lead-acid, lithium-ion and lithium iron phosphate (LFP) batteries. Each type of battery has specific advantages. The lifetime of a battery varies, depending on the operating regime and conditions, but is typically between 5 and 15 years depending on the technology, usage and maintenance. For some specific applications – typically, water pumping - no storage battery is needed, and energy is consumed as it is generated.

A charge controller (or regulator) is used to maintain the battery at the highest possible state of charge and provide the user with the required quantity of electricity, while protecting the battery from deep discharge or overcharging. Some charge controllers also have integrated MPP trackers to maximize the PV electricity generated. If there is a requirement for AC electricity, a "standalone inverter" can supply conventional AC appliances.

Off-grid domestic systems provide electricity to households and villages that are not connected to the utility electricity network. They provide electricity for lighting, refrigeration and other low power loads, have been installed worldwide and are increasingly the most competitive technology to meet the energy demands of off-grid communities.

Off-grid non-domestic installations were the first commercial application for terrestrial PV systems. They provide power for a wide range of applications, such as telecommunications, water pumping, vaccine refrigeration and navigational aids. These are applications where small amounts of electricity have a high value, thus making PV commercially cost competitive with other small generating sources.

METHODOLOGY FOR THE MAIN PV MARKET DEVELOPMENT INDICATORS

This report counts all PV installations, both grid-connected and reported off-grid installations. By convention, the numbers reported refer to the nominal power of PV systems installed. These are expressed in W (or Wp) or Wdc. Several methodological steps are taken when compiling data.

Power capacity reported in AC is converted to DC (nominal) power when necessary to calculate the most precise installation numbers every year: Some countries report the power output of the PV inverter or even the power of the grid connection. The difference between the standard DC Power (in Wp) and the AC power can range from as little as 5 % (conversion losses) to as much as 40% (for instance some grid regulations limit output to as little as 65% of the peak power from the PV system, but also higher DC/AC ratios reflect the evolution of utility-scale PV systems). For some countries, this means publishing different values to official data – for example, China's National Energy Administration (NEA) publishes in AC and PVPS applies a conversion ratio from AC to DC. A range of values is often provided to account for uncertainty in AC/DC conversion ratios, in particular with regards to new utility scale capacity in China, where the minimal annual volume considers official China reporting, and the maximal annual volume considers a further 47.8 GW that could have been installed considering the uncertainty surrounding official conversion ratios from AC to DC of utility scale systems. For many figures, these two values have been represented with full (minimum) and additional shaded (maximum) bars. If no range is specified, compiled data refers to the higher totals for China.

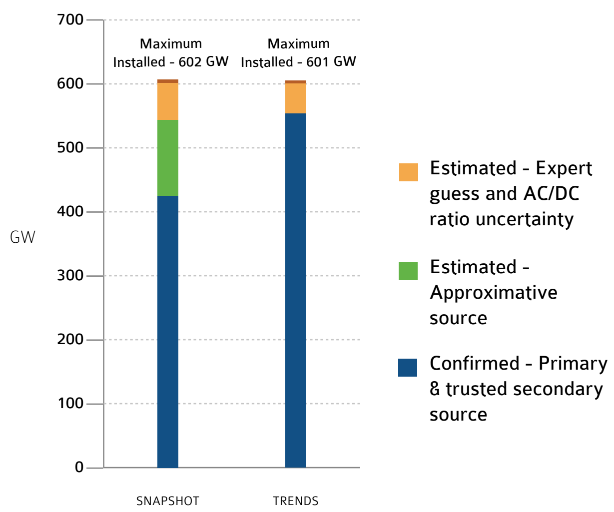
Inclusion of countries in geographical or political blocs and regions (see Annex 4): for tables and graph reporting data for major markets, data from member countries of the European Union is reported. Unless specified otherwise, the term Europe includes all countries on the continent. The European Commission is a member of the IEA PVPS however this report no longer counts all EU members in IEA PVPS blocs unless specified. Chinese Taipei refers to the Taiwanese economic region, Türkiye is included in Europe, and Korea refers to South Korea.

Global data should be considered as indications rather than exact statistics. Data from countries outside of the IEA PVPS network have been obtained through different sources, some of them based on custom trade statistics.

As the PV market grows constantly, reporting of PV installations is becoming more complex. IEA PVPS has decided to count all PV installations, both grid-connected and off-grid, when numbers are reported, and to estimate the remaining part on unreported installations. For countries with historically significant capacity and good reporting, a slow yet growing gap between shipped/imported capacity and installed capacity can be attributed to several factors including conversion factors from AC to DC, repowering and decommissioning. The extremely fast paced development of micro systems (often called plug&play or balcony systems) with only a few modules, whilst not significant in overall volumes is symptomatic of the development of often unreported systems reaching the market and sometimes being invisible to distribution system operators (DSO) and data collection. Of those countries that do have (sometimes partial) data on micro systems, Germany reached 1 million / 1 GW in June 2025, France declared more than 100 000 units in 2024 and China estimates a potential domestic market of nearly 70 GW. Conversely, plug&play systems are not yet legal in Japan

Other market evolutions such as off-grid applications are difficult to track even in member countries, and significant growth in installations in third countries without a robust reporting system is also a likely source of underreporting. In light of this, reporting here considers reported and expert estimates of new commissioned capacity as well as probable unreported volumes installed in one of the above contexts. Whilst global estimations published in the Snapshot in April 2025 and volumes in this publication are similar, many countries have revised annual installed volumes, in particular Australia, Spain, Singapore and Vietnam.

FIGURE 1.1: COMMISSIONED VOLUMES 2024 - FIRST ESTIMATIONS AND CONSOLIDATED DATA



SOURCE: IEA PVPS & OTHERS

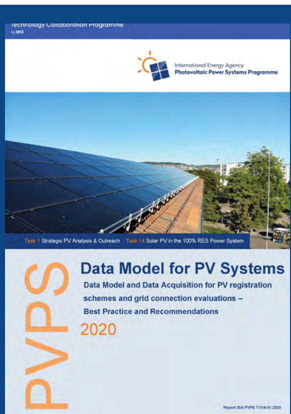
two

PV MARKET DEVELOPMENT TRENDS

Over 2.26 TW of PV plants have been installed globally, of which over 47% has been installed in the past three years. In 2024, more than 35 countries had a GW-scale annual market. Whilst the number of national markets with measurable contributions to global PV capacity is increasing every year, the concentration of the market in China over the past three years has decreased their relative importance.

A large majority of PV installations are grid-connected and feed electricity into either the consumer's internal electrical circuit or the electrical grid. PV installation data is reported in DC by default in this report, and this report converts any data officially reported in AC to DC to maintain coherency. When official reporting is in AC, announced capacities may be specified as MWac or MWdc in this report, if necessary, however by default, MW implies MWdc. See Chapter 1 for more information on data conversion methodology, uncertainty and in particular the impact on evaluations of China market figures.For more information on registering PV installations, download the IEA PVPS report on registering PV installations.

Download the "Data Model for PV Systems" reports



THE GLOBAL INSTALLED CAPACITY

Global PV installed capacity (GW)

+29% YoY growth

At the end of 2024, the cumulative global installed capacity reached 2 261 GW[1] - consistent with the preliminary estimation of 2 246 GW published in the IEA-PVPS Snapshot of Global PV Markets 2024 in April of this year.

It appears that 553.3 GW represented the **minimum** capacity based on trustable sources, and 601.1 GW represented the **most probable** capacity installed during 2024. This volume is a 29% increase compared to 2023, which was almost double that of 2022, itself well above 2021 volumes – resulting from a combination of increased action on climate imperatives, plummeting module costs and actions in China to absorb manufacturing capacity.

1. China's National Energy Administration (NEA) publishes in AC and PVPS applies a conversion ratio from AC to DC. A range of values is often provided to account for uncertainty in AC/DC conversion ratios, in particular with regards to new utility scale capacity in China, where the minimal annual volume considers official China reporting and the maximal annual volume considers a further 47.8 GW that could have been installed considering the uncertainty surrounding official conversion ratios from AC to DC of Utility scale systems. For many figures, these two values have been represented with full (minimum) and additional shaded (maximum) bars. If no range is specified, compiled data refers to the higher totals with Official China reporting values.

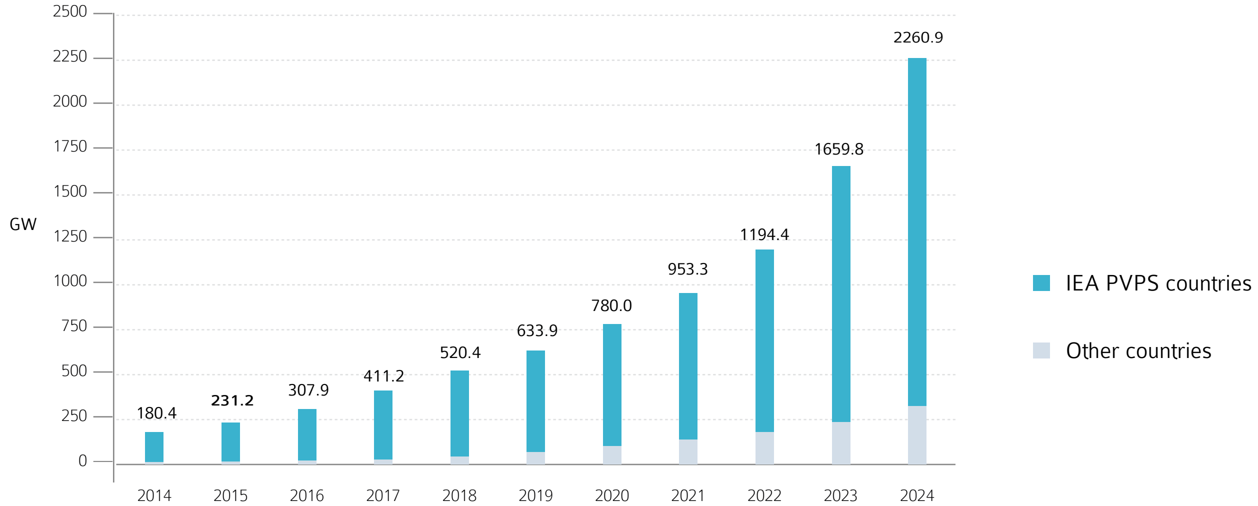
THE GLOBAL INSTALLED CAPACITY / CONTINUED

Among the trustable sources, the group of IEA PVPS[2] countries represented 1 937 GW of the global installed capacity. The IEA PVPS participating countries are 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, Türkiye, the United Kingdom (UK), and the USA. The European Commission is a member of the IEA PVPS and, as such, in this report its member countries are counted in IEA PVPS block.

2. For the purpose of this report, IEA PVPS countries are those that are members in their own right – or, as occasionally mentioned explicitly those that are a member in their own right or through the adhesion of the EC.

The other key markets that have been considered and which are not part of the IEA PVPS Programme represented a total cumulative capacity of 323.5 GW at the end of 2024. Amongst them, Brazil (52.1 GW), Vietnam (25.4 GW) and Pakistan (22.4 GW) scored the three first places. These countries represented from 6.5% (Pakistan) to 15% (Brazil) of the cumulative non-IEA PVPS capacity. Other non-IEA PVPS countries to have significant cumulative volumes include MENA countries with world-record size systems coming progressively online such as the UAE (7.6 GW) and Saudi Arabia (6.7 GW). In Asia, Chinese Taipei stood at a cumulative installed capacity of 14.3 GW. In Europe, Poland (21.3 GW) and Greece (9.7 GW) are the largest cumulative markets, followed by Ukraine (7.1 GW), although here the market has stalled given the ongoing conflict. Another ten non-IEA PVPS European countries have cumulative capacity over 2 GW.

FIGURE 2.1: EVOLUTION OF CUMULATIVE PV INSTALLATIONS



SOURCE: IEA PVPS & OTHERS

PV PENETRATION PER CAPITA

PV penetration can be measured either as a ratio of Wp per capita or kWh generated to meet a countries electricity demand – here we look at the volume of PV capacity relative to the country's population, indicating the relative efforts made by different countries.

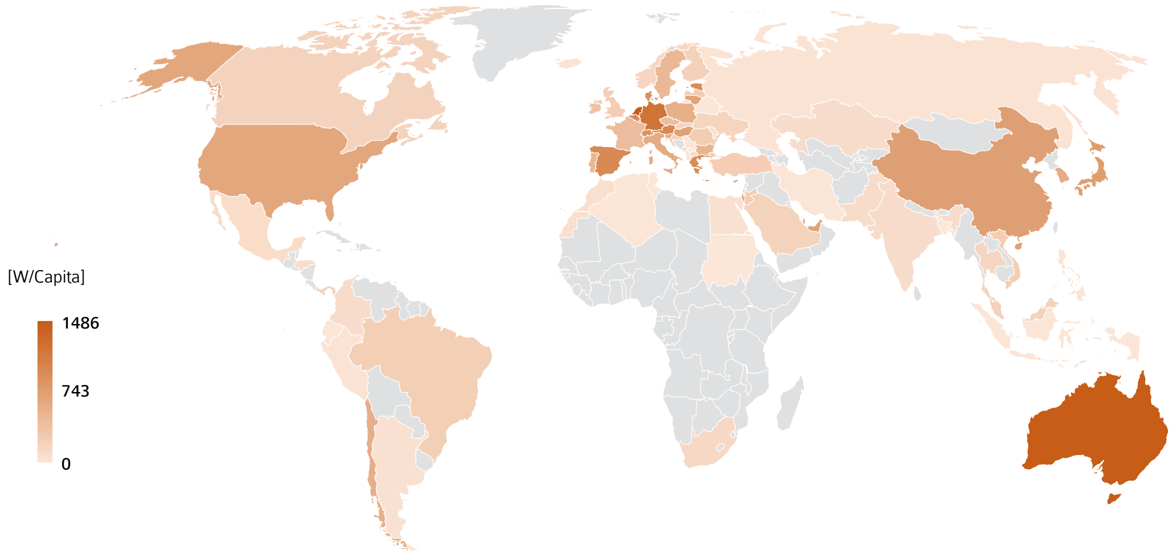
In 2024, the Netherlands surpassed Australia reaching the highest installed PV capacity per inhabitant with 1 486 W/cap (up 9.4% on 2023) in IEA-PVPS and surveyed countries. Australia is second with 1 463 W/cap (+25%). Germany (1 203 W/cap), Belgium (982 W/cap), Austria (970 W/cap) and Greece (938 W/cap) kept their top spots. Some big utility-scale systems commissioned in 2023 have allowed the UAE to significantly increase their rate, standing at 703 W/cap in 2024. Another 21 countries now have more than 500 W/cap, including the USA. With the large volumes installed in China, their penetration rate continued to increase reaching 749 W/cap. Of the largest country markets, India (86 W/cap) and Brazil (246 W/cap) still lag behind.

Typical residential systems have modules with an individual power of 435 Wp to 550 Wp – and now nearly 35 countries have the equivalent of 1 to 3 modules installed per person.

Both **Australia** and the **Netherlands** have installed more than 1 400 W/cap.

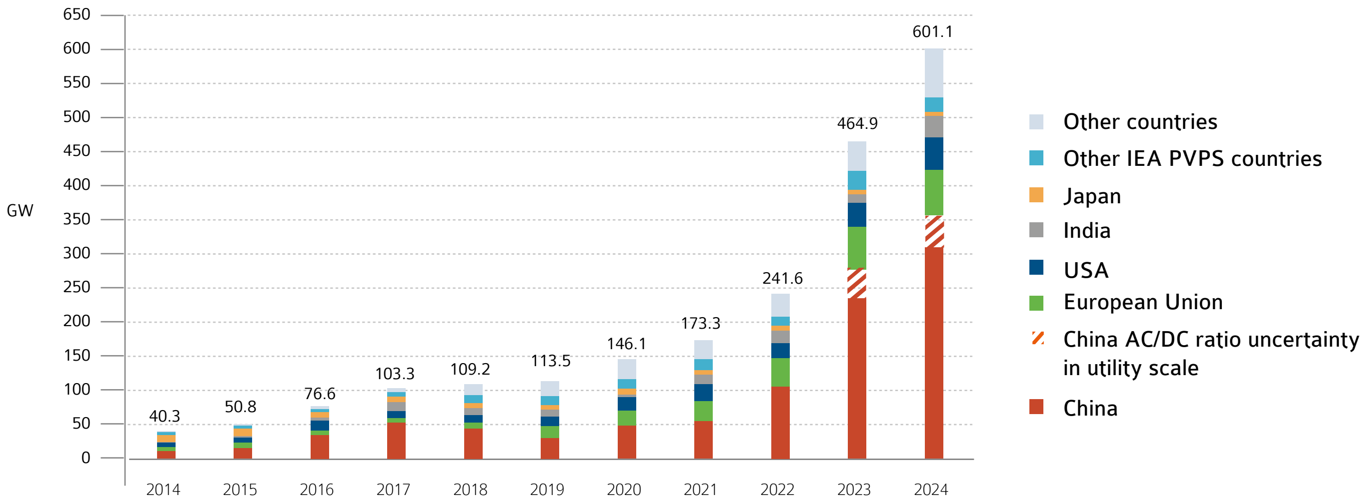
THE GLOBAL INSTALLED CAPACITY / CONTINUED

FIGURE 2.2: PV PENETRATION PER CAPITA IN 2024



SOURCE: IEA PVPS & OTHERS

FIGURE 2.3: EVOLUTION OF ANNUAL PV INSTALLATIONS IN MAJOR MARKETS



SOURCE: IEA PVPS & OTHERS

THE GLOBAL INSTALLED CAPACITY / CONTINUED

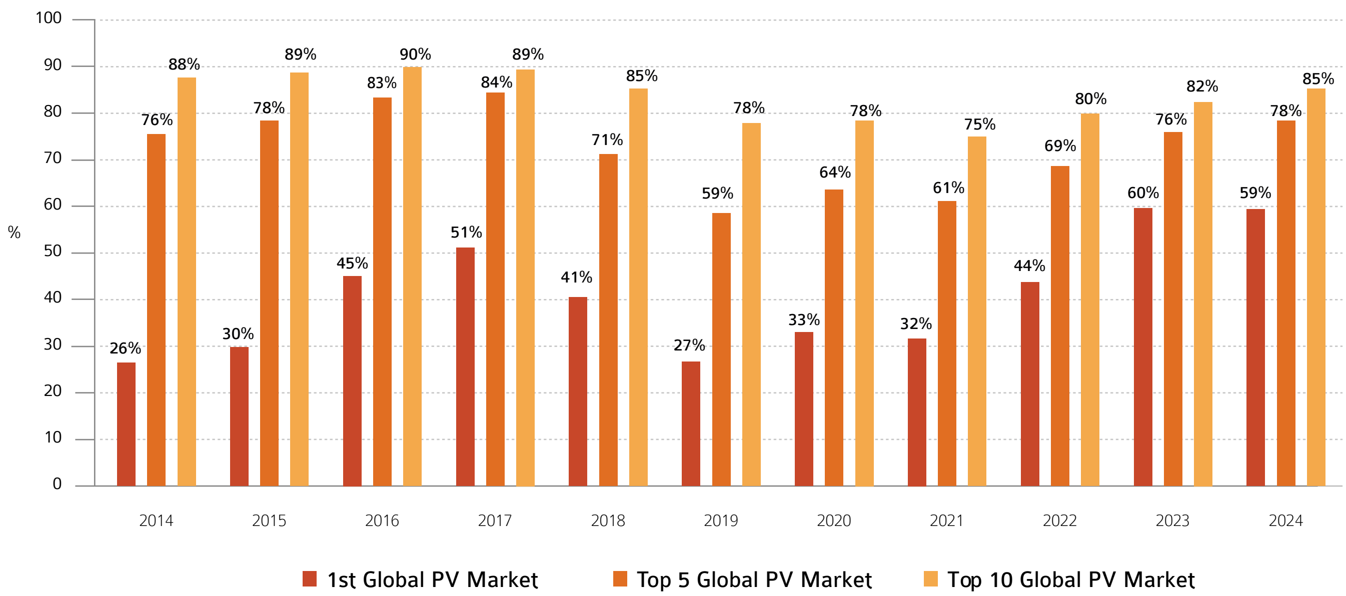
The IEA PVPS countries installed at least 470.3 GW but probably as much as 518.1 GW in 2024. While they are more difficult to track with a high level of certainty, installations in non-IEA PVPS countries contributed an estimated amount of 87.4 GW (including all EU countries). After two years of what was perceived as strong growth, 2023 beat all the records, nearly doubling 2022 annual capacity as module prices dropped. In 2024, the annual market continue to grow as consumer, and investor confidence in the ability of PV to provide reliable and stable electricity generation costs as a shelter from electricity market fluctuations was maintained.

Much of the growth has been achieved in China, where installed volumes jumped through the year, although they struggled to keep up with the volume of manufacturing capacity available.

Between 309.4 GW and 357.3 GW was installed (converted from China's National Energy Administration's AC figures and depending on the AC/DC conversion ratio used). Whilst there is an increasingly large uncertainty around the nominal capacity installed in utility-scale plants (the inverter/module ratio is estimated based on industry practices and a few percentage points error can lead to tens of GW of difference in estimated volumes), it is clear that the Chinese market was driven by the centralised segment this year, with just 38.2% of new capacity in the distributed segment. The Chinese market represented 59.4% of the global installations in 2024 This market dominance is similar to the role Germany played through the mid-late 2000's, and the long-term impacts are difficult to judge. The cumulative capacity installed in China reached at least 958.5.GW and as much as 1 048.5 GW.

Taken as a bloc, the **European Union** would come in second after China in terms of annual installed capacity, maintaining strong growth rates for the fifth year in a row. The combined annual new capacity was 66.0 GW, led by **Germany** with 17.2 GW, **Spain** with a steady 8.7 GW and strong contributions from **Italy** (6.7 GW), **Poland** (4.2 GW) and **France** (6.0 GW).

FIGURE 2.4: EVOLUTION OF MARKET SHARE OF TOP COUNTRIES



SOURCE: IEA PVPS & OTHERS

THE GLOBAL INSTALLED CAPACITY / CONTINUED

The USA market grew nearly 40% reaching 47.1 GW, after a having already experienced a 50% increase in 2023. Some of the issues that had hindered the 2022 market seems to have been partially resolved, including installation backlogs due to supply chain issues. The market remains a utility-scale market, with 40.3 GW or just over 85% of new capacity centralised. The decentralised market saw 6.7 GW installed, slightly below 2023's 9.6 GW. By the end of 2024, the USA reached 225 GW of cumulative installed capacity.

With strong growth India passed Germany to reach third place with 31.9 GW installed, up from the previous year's 13.0 GW, for a total cumulative capacity of 124.6 GW. Very strong growth in Pakistan (18.0 GW) has it in fourth place ahead of Germany (17.2 GW, hitting 100.4 GW cumulative).

With the dominance of the Chinese market, it is no surprise that the market share of the top countries is becoming more and more elevated - smaller markets are contributing proportionally less to global installation numbers than the major markets. China has done much to absorb the results of its manufacturing capacity growth.

Whilst the market in Brazil didn't maintain the high growth rates of the previous four years, and it slipped to 6th place, it was still a growth market with 14.3 GW, reaching 52.1 GW cumulative capacity, confirming its place as a globally important market. Spain in 7th place (8.7 GW for 48.3 GW cumulative capacity) remained steady. Italy remained in the top 10, with 6.7 GW new capacity for a cumulative capacity of 37 GW. Poland had similar volumes in 2024 to 2023: with 4.2 GW annual for 21.3 GW cumulative capacity. In the Netherlands 3.4 W of new installations allowed to reach a total of 26.7 GW.

Together, these 10 markets cover around 85% of the 2024 annual world market, a sign that the growth of the global PV market has been driven by a limited number of countries once again. Market concentration has been fuelling fears for the market's stability in the past if one of the top three or top five markets would experience a slowdown, although the past years have shown that when one market slows, another is often in growth (witness USA/India, for example). As shown in Figure 2.4, the market concentration steadily decreased in 2019 before growing again in 2020, stabilising in 2021, then growing for four years in a row, due to the growth of the Chinese PV market. As new markets are starting to emerge, the concentration of the global PV market minus China reduces, and therefore the risks. However, the size of the Chinese PV market continues to shape the evolution of the PV market as a whole. As we have seen in 2019, the global growth was limited due to the decline of the first market, which almost wiped out the global growth, while in 2022, 2023 and 2024, China's installations maximized global growth.

TABLE 2.1: EVOLUTION OF TOP 10 MARKETS

RANKING	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA
2	JAPAN	JAPAN	USA	INDIA	INDIA	USA	USA	USA	USA	USA	USA
3	USA	USA	JAPAN	USA	USA	INDIA	VIETNAM	INDIA	INDIA	GERMANY	INDIA
4	UK	UK	INDIA	JAPAN	JAPAN	JAPAN	JAPAN	JAPAN	BRAZIL	INDIA	PAKISTAN
5	GERMANY	INDIA	UK	TÜRKIYE	VIETNAM	VIETNAM	GERMANY	BRAZIL	SPAIN	BRAZIL	GERMANY
6	FRANCE	GERMANY	GERMANY	GERMANY	AUSTRALIA	SPAIN	AUSTRALIA	GERMANY	GERMANY	SPAIN	BRAZIL
7	SOUTH AFRICA	KOREA	THAILAND	KOREA	TÜRKIYE	AUSTRALIA	KOREA	AUSTRALIA	JAPAN	JAPAN	SPAIN
8	KOREA	FRANCE	KOREA	AUSTRALIA	GERMANY	KOREA	INDIA	SPAIN	POLAND	ITALY	ITALY
9	AUSTRALIA	AUSTRALIA	AUSTRALIA	FRANCE	MEXICO	GERMANY	BRAZIL	KOREA	AUSTRALIA	POLAND	FRANCE
10	INDIA	CANADA	TÜRKIYE	BRAZIL	KOREA	UKRAINE	SPAIN	POLAND	NETHER-LANDS	TÜRKIYE	JAPAN
RANKING EU	3	3	4	4	2	2	2	2	2	2	2
MARKET LEVEL TO ACCESS THE TOP 10											
	865 MW	675 MW	818 MW	1067 MW	2265 MW	3537 MW	3528 MW	3710 MW	4200 MW	4827 MW	5620 MW

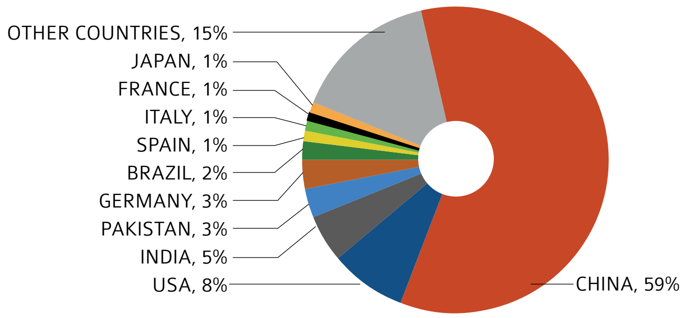
SOURCE: IEA PVPS & OTHERS

THE GLOBAL INSTALLED CAPACITY / CONTINUED

The level of installations required to be included in the top 10 (country wise) has increased steadily since 2014: from 0.87 GW to 2.3 GW in 2018, and around 3.5 GW since 2020, increasing to a similar extent as the year before to 5.6 GW in 2024. This reflects the global growth trend of the solar PV market, but also its variations from one year to another. Whilst this increase could be considered a significant size, it is still extremely low compared to the volume in China; had all markets across the world grown at the same rate as in China, this minimum value would be closer to 10 GW than 5 GW. Other countries that installed several GW in 2024 and were found in the top 10 countries in the past couldn't reach the volumes required this year, but remained close: Türkiye, Poland, and Australia installed more than 4 GW in 2024 and have experienced stable markets or slightly decreasing installation rates. Preliminary indications point to a stabilisation in those markets that have reached market competitiveness across most segments.
Over 30 countries had more than 1 GW newly installed in 2024, spread across all continents, with the notable arrival of several countries in the Middle East and Africa.

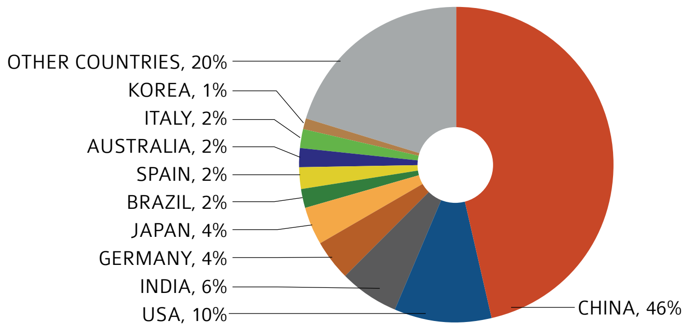
As detailed above, the IEA PVPS choice consists in reporting DC capacities. An estimate of AC capacities would put the new installed capacities number between 400 to 501 GWac in 2024. This number (in the same way as the DC number) is an approximation of the reality and represents an estimated value of the maximum power that all PV systems globally could generate instantaneously, assuming they would all produce at the same time. This number is indicative and should in no case be used for energy production calculation.

FIGURE 2.5: GLOBAL PV MARKET IN 2024



SOURCE: IEA PVPS & OTHERS

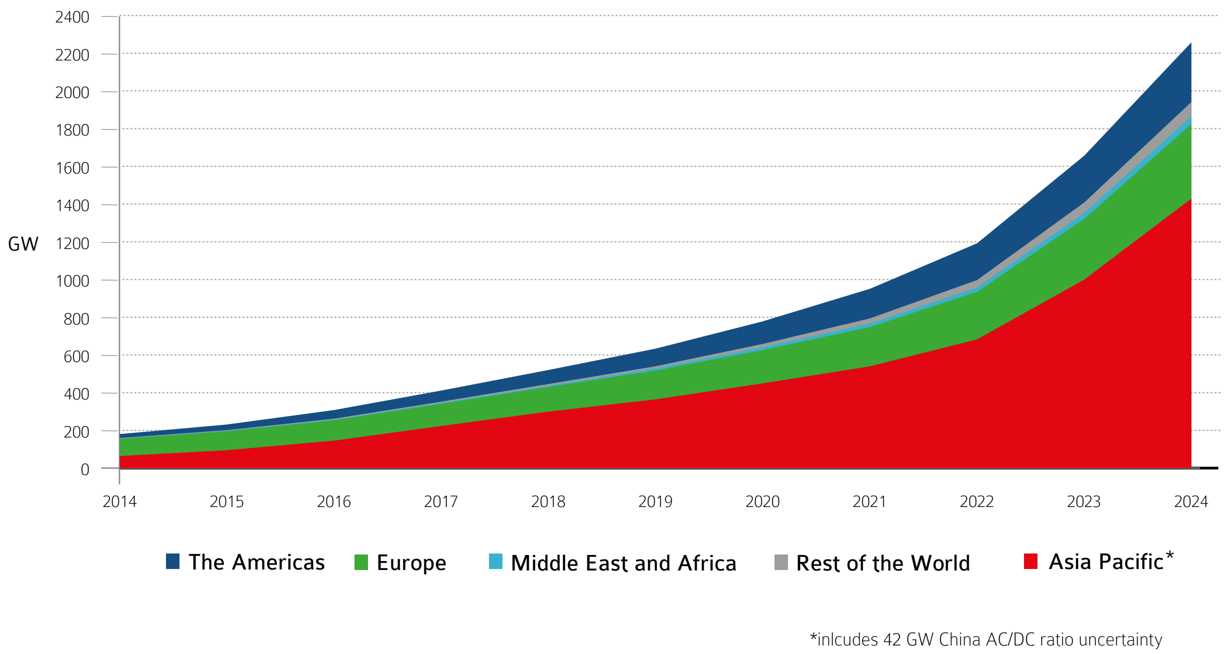
FIGURE 2.6: CUMULATIVE PV CAPACITY END 2024



SOURCE: IEA PVPS & OTHERS

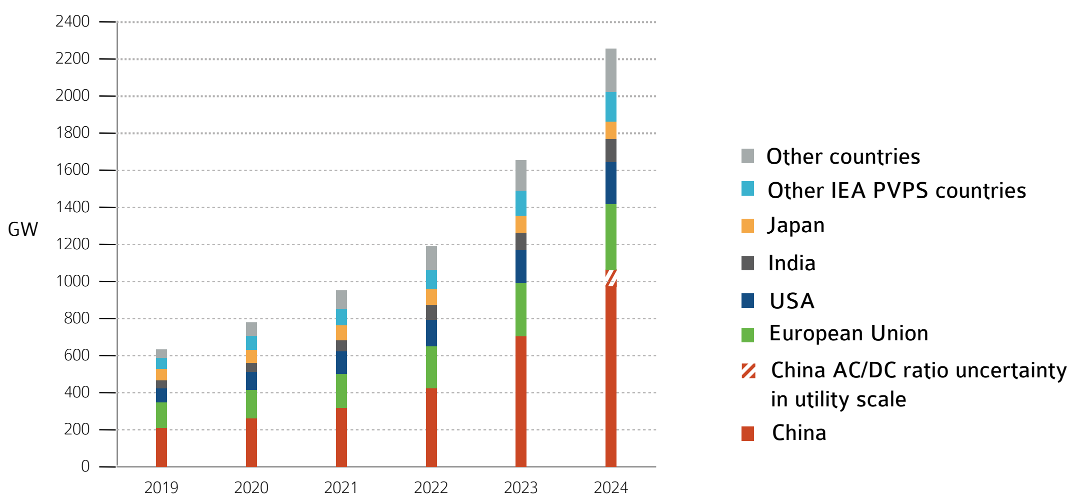
THE GLOBAL INSTALLED CAPACITY / CONTINUED

FIGURE 2.7: EVOLUTION OF REGIONAL PV INSTALLATIONS



SOURCE: IEA PVPS & OTHERS

FIGURE 2.8: 2019-2024 GROWTH IN MAJOR MARKETS



SOURCE: IEA PVPS & OTHERS

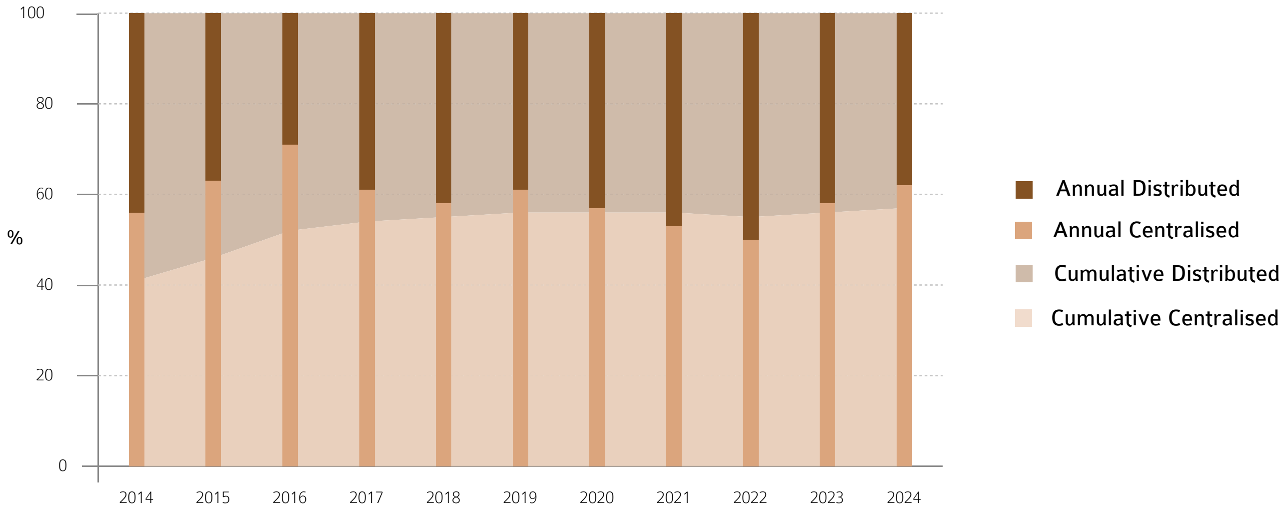
PV MARKET SEGMENTS

We consider three market segments in this report; centralised (large systems above a few MW up to utility-scale and mostly feeding electricity to the grid), distributed (anything below this connected to the grid and connected to a consumption point) and off-grid. Off-grid has been included in distributed volumes in this report's market statistics. With different reporting systems from one country to another, there is no specific system size separating centralised from distributed, however, the segmentation is undertaken in most markets by governments, utilities and industry associations as the impacts are quite different, affecting grid connection, grid capacity, fiscality and taxation and the ability to properly count and evaluate capacities. Additionally, for some markets, the conversion of AC power to DC power is built on different conversion coefficients, in line with industry practices.

Overall, it is estimated that the centralised segment (62% or 373.0 GW) slightly outweighed the distributed segment (38% or 228.1 GW) in new annual capacity in 2024, with a swing towards more centralised systems – although it must be noted that the 47.8 GW of probable extra capacity in China is included in the centralised volumes. This globally balanced result is on the one hand a reflection of the mostly balanced Chinese market but belies significant differences in other major markets.

The share of utility-scale installations represented around 57% of cumulative installed capacity in 2024, remaining stable compared to last year. Off-grid and edge-of-the-grid applications are increasingly integrated into distributed installations, with little ability in most countries to track volume.

FIGURE 2.9: ANNUAL SHARE OF CENTRALISED AND DISTRIBUTED GRID-CONNECTED INSTALLATIONS 2014-2024



SOURCE: IEA PVPS & OTHERS

Except for the European market that incentivized residential segments from the start, most of the major PV developments in emerging PV markets tended to come from utility-scale PV in the past. The drop in module prices and the increasing attractivity of self-consumption across the world is likely to change this, as was demonstrated in Brazil and Vietnam, and South Africa.

UTILITY-SCALE PV

Utility-scale PV plants are in general ground-mounted (or floating) installations. In some cases, they could be used for self-consumption when close to large consumption centres or industries (mining sites), but generally they feed electricity directly into the grid. The development of utility-scale applications continues to grow in both new and established PV markets, and despite market competitiveness in many countries, competitive tendering processes are used to select the most competitive projects, to guide the types of land used or encourage other aspects.

PV MARKET SEGMENTS / CONTINUED

TABLE 2.2: TOP 10 COUNTRIES FOR CENTRALISED PV INSTALLED IN 2024

COUNTRY	GW
CHINA*	239.1
USA	40.3
INDIA	23.9
PAKISTAN	9.0
GERMANY	6.5
BRAZIL	5.7
SAUDI ARABIA	3.8
JAPAN	2.3
ITALY	2.2
AUSTRALIA	2.0

*includes 42GW AC/DC conversion uncertain volumes

SOURCE: IEA PVPS & OTHERS

TABLE 2.3: TOP 10 COUNTRIES FOR CENTRALISED PV CUMULATIVE CAPACITY IN 2024

COUNTRY	GW
CHINA*	674.3
USA	158.1
INDIA	100.8
JAPAN	39.1
SPAIN	38.6
KOREA	26.3
GERMANY	25.4
BRAZIL	17.1
NETHERLANDS	15.4
VIETNAM	14.7

*includes 42GW AC/DC conversion uncertain volumes

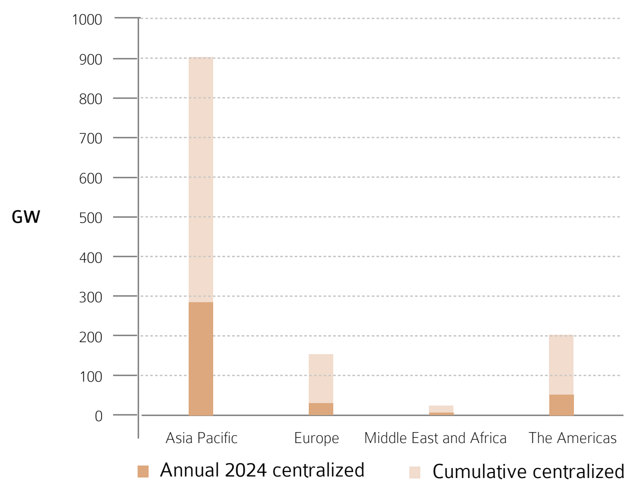
SOURCE: IEA PVPS & OTHERS

Utility-scale systems are providing a majority of new capacity in some key markets such as India, the USA, Spain and Korea. The commissioning of very large-scale utility systems in the MENA region. Saudi Arabia and the UAE in 2023 ahead of a number of other countries in the coming years will add new countries that are driven by centralised systems.

Merchant PV, where PV electricity is directly sold to electricity markets and corporate PPAs, where it is directly sold to corporate consumers continues to grow in many countries. Trials conducted in the past years, especially in 2022 pulled by the high electricity markets costs, gave developers and investors' confidence in the ability to create viable projects. Whilst merchant PV is in its early phases, the impacts of negative prices and price cannibalisation are two subjects that will be closely monitored by investors over the next few years. In parallel, the limitations that are already being seen due to grid congestion, social acceptance or strict environmental impact study requirements remain important barriers. Experience has demonstrated that securing grid connection can lead project developers to tender very low bids just to secure grid connection capacity (Portugal, Spain), whilst some countries have had to specifically invest in and develop grid capacity to ensure the continued development of utility-scale systems (Australia, Austria, Brazil, France).

Utility scale plants are not homogeneous and vary in size from a few MW to over 1 000 MW; some may be installed on fixed tilt supports, others on single or dual axis trackers to maximise production. Systems installed on water bodies (floating PV) are becoming standardized, as is the development of lower density systems on grazing land. The use of bifacial PV modules is increasing relatively fast as well. The addition of co-located storage (battery) systems is increasingly common, either pushed by specific rules in tenders or by attractive conditions for grid services and wholesale markets (Australia, Germany, USA). In 2024, centralised PV amounted to 373.0 GW (62% of new capacity) globally and the total installed capacity for all of these applications amounted to 1 300 GW, representing 58% of the cumulative installed capacity.

FIGURE 2.10: CENTRALISED PV - CUMULATIVE AND ANNUAL INSTALLED CAPACITY PER REGION 2024



SOURCE: IEA PVPS & OTHERS

PV MARKET SEGMENTS / CONTINUED

DISTRIBUTED PV

Distributed PV (also called decentralised PV) are PV systems that are either smaller systems connected to the distribution grid (from a few hundred watt peak to a few MW), most often installed on buildings or systems installed with the goal of supplying a local consumer, (for example, directly through self-consumption). Historically distributed PV launched the massification of the PV industry in Germany and other early adopting countries; now self-consumption is a market driver for distributed PV in many countries.

PROSUMERS, POWERING THE DISTRIBUTED PV MARKET ACROSS THE WORLD

Prosumers are consumers producing part (or all) of their own electricity consumption – and whilst technically any generator in proximity to a consumption point will feed that consumption point, prosumer as a term is reserved for situations where this self-consumption is both based on electron flows and financial flows i.e., the consumer is on the same side of the meter as the generator. The development of prosumer markets is occurring organically in countries where the competitiveness of PV generated kWh's matches those of residential and commercial electricity prices – although policy and regulatory frameworks have often needed to be adapted, in particular to allow prosumers to inject excess generation into the grid. In other countries, the cost of other support mechanisms has pushed policy changes. After the development of simple prosumer policies and models, more complex collective and distributed (virtual) self-consumption models and frameworks for residential and commercial electricity customers are being implemented

The distributed market had a volume of 13 GW to 22 GW from 2010 to 2016, until China succeeded in developing its own distributed market, roughly doubling distributed PV volumes from 2016 to 2018. In 2024, this market reached 228.1 GW, up from 193.5 GW in 2023 and 119.5 GW in 2022.

PV MARKET SEGMENTS / CONTINUED

TABLE 2.4: TOP 10 COUNTRIES FOR DISTRIBUTED PV INSTALLED IN 2024

COUNTRY	GW
CHINA	118.2
GERMANY	10.7
PAKISTAN	9.0
BRAZIL	8.7
INDIA	8.0
USA	6.7
ITALY	4.4
FRANCE	4.1
JAPAN	3.3
TÜRKIYE	3.3

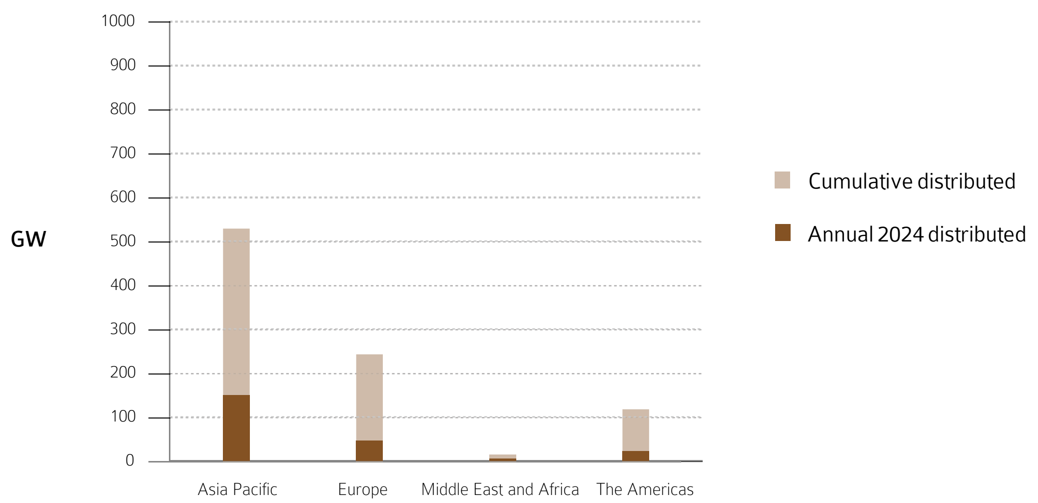
SOURCE: IEA PVPS & OTHERS

TABLE 2.5: TOP 10 COUNTRIES FOR DISTRIBUTED PV TOTAL INSTALLED CAPACITY IN 2024

COUNTRY	GW
CHINA	374.2
GERMANY	73.9
USA	66.9
JAPAN	57.9
BRAZIL	35.0
AUSTRALIA	26.4
ITALY	25.4
INDIA	23.7
TÜRKIYE	17.1
FRANCE	16.8

SOURCE: IEA PVPS & OTHERS

FIGURE 2.11: DISTRIBUTED PV - CUMULATIVE AND ANNUAL INSTALLED CAPACITY PER REGION 2024



SOURCE IEA PVPS & OTHERS

DUAL USAGE AND EMERGING PV MARKET SEGMENTS

The installation of photovoltaic installations on infrastructure or land used for other purpose is a response to the competition for land implied by the massive development of new PV capacities, and the resulting need to ensure social acceptance. The availability of land surfaces and the acceptability of their usage for PV are key considerations in an increasing number of countries - typically where there is existing or spreading urbanisation with a consequent loss of biodiversity, sustained or regular loss of agricultural land or a strong push to preserve heritage buildings and natural landscapes for aesthetic and cultural reasons.

For utility scale PV and ground-mounted installations, competition has arisen between other uses and electricity production, dominated by conflict for agricultural land. By combining agricultural and energy production on the same surface, agrivoltaics seeks to propose a desirable acceptable alternative. Floating solar photovoltaics uses the available surfaces on natural and artificial lakes and reservoirs, and is a particularly dynamic market segment in Asian regions where the tension on land use is strong. These market trends in the centralized segment are strong and underpinned by the same imperative to promote compatible dual land use. The use of other infrastructure such as canopies on canals or noise barriers along highways is also becoming more common, driven by the same motivating factors of access to land without generating conflict or opposition.

For distributed PV, integrating PV into and onto buildings has been a goal for many years and considered a natural solution to the imperative of reducing land use, bringing generation to the point of consumption and reducing social resistance to PV. Specific products have been developed for a long time - and encouraging PV on buildings has even been the mainstay of public policies for the distributed segment in the past in some countries (most notably France). In particular, the European Union is encouraging member states to develop ambitious targets. It can be attractive because it uses existing buildings but also can lead to a more harmonious integration in the environment, reducing social resistance.

AGRIVOLTAICS

The development of PV on agricultural land has been a reality since the utility-scale PV started. In some cases, crops were replaced by photovoltaics and land use shifted towards electricity production; in other cases, low intensity grazing continued around modules. Agrivoltaics, however, proposes a different approach by using land for both food and energy production at the same time. As PV penetration rates increase in many countries, competition for land can limit PV development - some countries have even regulated access to agricultural land for PV through legislation or conditions in tenders (Italy, France, Korea). Catalonia, (Spain) introduced official guidelines for agrivoltaics that require projects to maintain at least 60% of pre-installation crop yield, limit soil disturbance, and cap PV coverage to between 15% and 20% of the land area. In Czechia, new regulations allow PV deployment in orchards, vineyards, and hopyards without changing land zoning. These rules include a 10% surface limit but no mandatory yield requirement, although vertical PV systems are currently excluded. In Japan, the government suspended feed-in tariffs for 342 agrivoltaic projects in April 2024 following violations of updated regulations governing the use of agricultural land.

The potential for PV on agricultural land, and how this segment can contribute to achieving renewable energy targets has been studied in different regions, and whilst government and developer interest has increased, so has reluctance or opposition from farmers and the general public. To give an example of the potential of this segment, in the European Union, covering just 1% of agricultural land with agrivoltaic systems could deliver about 944 GWp of solar capacity (over 40% of the EU's electricity demand). In India alone, recent studies estimate a technical potential of approximately 3 200 GWp, just the state of Punjab could have around 871 GWp.

PV on agricultural land is implemented with different configurations and designs, and sometimes specific vocabularies:

- PV systems above crops or plants; the PV system allows for growing different kinds of crops but with reduced solar insulation and could provide new services and business models - such as protection against hazards that damage crops (hail, excessive sun), water saving though reduced evaporation, and environments adapted to crops that would not have been possible in the actual or future climate conditions. This dual use requires specific technical solutions such as elevated PV plants, where either the density of the panels is reduced and adapted to the crops needs or the panels are mobile and their position (tilt) is modified to maximize PV production or crop production depending on the weather conditions. The density can be adapted by the design of the PV plant by spreading modules out or by modifying the module itself to be semi-transparent.
- Crops, grassland, pollinator habitat and grazing can be hosted between the rows of PV plants. The systems must enable the land to maintain its agricultural vocation. The shade supplied by the systems can increase grass production and reduce animal (and worker) heat stress - indeed, in some countries increased shading for animals as temperatures increase because of climate change could be an important motivator. The design of the PV plant must be adapted to the activity: adequate space between the rows to allow agricultural machinery, the

DUAL USAGE AND EMERGING PV MARKET SEGMENTS / CONTINUED

right height, electrical and dust protection. Ground-mounted PV plants, some with trackers, are implemented at a utility-scale level. Vertical bifacial PV is also being tested in several plants, as the impact of the PV on the land available for the agricultural activity is very low.

- PV systems are also developed and integrated in greenhouses.

Even if there is significant potential for PV on agricultural lands, other factors must be taken into consideration. Food production security and agricultural sufficiency are generally the first priority, with the agricultural sector's economic balance, environmental impacts, social acceptance and water management also important factors.

System costs, profitability and agricultural benefits vary depending on the importance given to agricultural production compared to energy production. Support mechanisms and financial aid intensity can also vary accordingly. PV systems falling under the most restrictive definition of agrivoltaics typically receive higher incentives.

Generally, in the different frameworks and support mechanisms, two types of PV projects are considered:

- PV plants where some form of agricultural production is maintained. These systems are already economically viable and cost-effective. Energy production dominates but agricultural production is maintained. These projects often participate in the classic competitive tenders or negotiate PPAs.
- PV plants complying with advanced criteria where they enhance agricultural production and farmer revenue. Agricultural production profitability must dominate, and energy production is an added value. This type of plant requires being adapted to the specific crops underneath.

In China, a 192 MWp agrivoltaic system began operating in Yunnan Province. It integrates high-efficiency solar panels with agricultural activities on hilly terrain. In Sweden, the country's first large-scale agrivoltaic park with a capacity of 6 MW was inaugurated in Gullspång. It supports rotational farming of rapeseed, ley, and wheat while supplying clean electricity to a local vertical farm. In the USA, the first phase of a major 1.3 GWp agrivoltaic initiative began operation in Indiana. This initial phase, known as Mammoth North, has a capacity of 480 MWp.

A 69 MWp agrivoltaic facility in Germany that will deploy elevated solar panels over livestock grazing (in construction - it is expected to be operational in 2025). In Italy, 540 agrivoltaic projects were awarded through the country's first dedicated competitive tender, for a total of 1.5 GWp, primarily located in the countries south. A 9.6 MWp system near Bologna was commissioned during the year. France advanced two pilot projects; one in Poisy with a capacity of 250 kWp that integrates cattle grazing, and another in Camélia, a 100 kWp vertical installation designed to maintain meadow use while optimizing solar generation. Construction also began on a 1 MWp agrivoltaic plant in Isère. Meanwhile, a digital agrivoltaics map launched by SolarPower Europe highlights more than 200 projects across 10 European countries, totalling over 15 GWp in combined planned and operational capacity.

2024 important industry wide publications were prepared - IEA PVPS launched an Action Group on Agrivoltaics to promote international collaboration and consolidate best practices, with a global report planned for release in November 2025, and in Europe, SolarPower Europe published a practical agrivoltaics handbook outlining ten archetypes, viable business models, and environmental benefits. It also called on policymakers to simplify permitting procedures and expand incentives.

IIPV: INFRASTRUCTURE INTEGRATED PV

IIPV refers to PV implanted on or close to infrastructure; it can be used as a term to cover PV installed on any building or on or close to any element of the built environment, but is more commonly used to refer to PV installed on unused land close to transport infrastructures (along roads, highways and railways) and waterways (irrigation canals, banks, dikes, etc.).

There is a significant potential in these spaces – and as another dual-use of land, they provide an opportunity for PV surface with better social acceptance. The rapid decline in PV prices in recent years has meant the linear PV systems or specifically adapted supports have increased their competitiveness and created new opportunities for these innovative deployment solutions.

Vertical PV walls along roads, motorways and railways, whether or not integrated with noise barriers, have historically been developed in Europe (Switzerland, Germany, Austria, the Netherlands) and are attracting growing and continuous interest with new projects coming online in the past years around the world (Korea, USA, the Netherlands). The electricity generated by PV installations along roads could contribute to the decarbonisation of this sector as electric vehicles become the norm, by producing energy as close as possible to consumption.

Pilot and demonstration systems are underway for other innovative applications: PV canopies over bicycle paths and roads

DUAL USAGE AND EMERGING PV MARKET SEGMENTS / CONTINUED

The European Commission's Joint Research Centre (JRC) has assessed the potential for large-scale deployment of vertical solar panels along major roads and railways in Europe. The results reveal a total potential of 403 GWp within the European Union for this type of integration alone, compared to the EU's 2030 target of 750 GWp. The study also establishes that considering only railway lines, the total annual production of PV electricity could potentially reach 250% of the current annual electricity consumption of the EU rail network. This approach offers considerable potential to power the EU's energy needs while contributing to the decarbonisation of the transport sector.

(Germany, France) and on dikes (Netherlands). PV shade canopies on irrigation canals, developed in India since the 2010s, are slowly being deployed in regions subject to high evaporation rates (USA, Spain, even France). National railway companies and private developers are also announcing studies or pilot projects for PV along their networks (UK, France) on previously unexploited linear land, or even within the rails (Switzerland, France).

The types of systems (ground mounted, vertical, integrated into existing infrastructure, in canopies) are numerous and present different levels of technological, industrial and commercial maturity. One of the challenges of these installations lies in the fact that the support's initial function (noise barrier, sunshade) must be preserved while allowing the production of electricity. For those installations on linear land (long and narrow) technical and regulatory questions remain to be resolved, in particular with regards to the use of often public lands for private benefits, whilst the electrical architecture and connection possibilities must be studied to achieve both technical and economic viability.

FLOATING PV: CONTINUED GROWTH

In densely populated areas, the proximity of water bodies to load centers is often an advantage. Traditional land-based PV systems face competition for land use with industrial or agricultural activities or may not be economically viable due to the high cost of land. Japan was one of the early adopters of Floating PV (FPV), with over 200 projects. FPV is even possible in city states such as Singapore, and archipelagos such as Indonesia. The highest installed FPV capacity to date is deployed in China.

By the end of 2024, the global installed capacity of FPV systems is estimated to have reached approximately 8.7 GW. This represents a significant growth, with the capacity expanding from 7 GW in 2023.

In 2024, floating photovoltaic deployment saw significant growth across various regions, with both inland and offshore systems becoming operational, and the number of large-scale floating solar projects currently under construction or in advanced planning stages continues to grow. In Europe, Spain installed a 270 kW pilot system in the Canary Islands using innovative membrane technology. Norway commissioned a 124 kW offshore pilot in Risør, with plans to expand to 3 MW. In France, a 74.3 MW floating solar plant has been financed and is scheduled for inauguration in 2025. In Germany, a 1.8 MW FPV plant is being constructed on a gravel pit lake in Gilching.

In Asia, India commissioned a 126 MW floating solar project in Omkareshwar. Japan launched its first offshore FPV project in Tokyo Bay with an 80 kW to 100 kW systems in total powering electric vehicles and boats. Thailand completed a 1.8 MW FPV installation, expected to generate 2 650 MWh annually. China continues to lead with large-scale systems, including a 1 GW offshore FPV project in Shandong Province and a 400 MW project commissioned in August, and Chinese Taipei brought online a 440 MW offshore FPV system in Changhua County, capable of powering approximately 74 000 households. Korea has begun construction on a 47 MW floating solar project at Imha Dam. In the Philippines, 29 large-scale solar projects were approved between January and August 2024, including eight floating PV systems over 100 MW, ranging from 125.9 MW to 280 MW, in Laguna, Ilocos Norte, Negros Occidental, and Pampanga. In India, a 234 MW FPV system is in the bidding stage for installation on the Maithon Dam Reservoir in Jharkhand.

In addition to installed and planned projects, recent studies have highlighted the significant potential of FPV globally. In China, researchers estimated a theoretical capacity of up to 862.6 GW. In India, an Indo-German study estimated a technical potential of 206.7 GWp, with 30 GW expected to be deployed between 2024 and 2040, particularly in Madhya Pradesh and Maharashtra. According to Wood Mackenzie, global FPV capacity could reach 77 GW by 2033, with Asia-Pacific accounting for 57 GW. China, India, and Indonesia together are expected to install 31 GW. In Europe, Germany could reach 2.2 GW, followed by France at 1.2 GW and the Netherlands at 1 GW. In the USA, 0.7 GW is projected.

BIPV: UNLOCKING POTENTIAL IN A SPECIALIZED MARKET

While this report explores the evolution of the BIPV industry from a PV-centric and policy-driven point of view, it's crucial to recognize that the true transformative power of Building-Integrated Photovoltaics (BIPV) lies in architecture and urban design. BIPV is not simply a "variant" of PV technology, it is a construction material, a tool for urban renewal, and a bridge between energy and aesthetics. Its market trajectory must therefore be viewed not

DUAL USAGE AND EMERGING PV MARKET SEGMENTS /CONTINUED

only in kilowatts, but in its ability to shape cities that are sustainable, culturally accepted, and beautiful[1].

Market status

The European BIPV market is driven by countries such as France, Switzerland, Austria and Germany. By the end of 2024, France had approximately 100 MW of new BIPV installed capacity, followed by Switzerland (90 MW) and Austria (82 MW). In the early 2010s, BIPV adoption was stimulated by feed-in tariff incentives like France's premium of 0.25EUR/kWh on integrated systems and Italy's Conto Energia scheme, which supported over 18 GW of PV, including 2.5 GW of BIPV. Although few European countries currently maintain BIPV-specific support schemes, those that do have notable outcomes. Austria's EAG investment subsidy for BIPV offers a +30% bonus relative to standard PV for innovative PV systems and has significantly grown their BIPV market since 2023. Switzerland's one-off investment subsidies includ a tilt-angle bonus to favour vertical systems. Overall, Europe recorded approximately 350 MW of installed capacity in 2024, representing <1% of distributed PV capacity installed during that year. This figure contrasts with the reality in certain countries such as Switzerland where BIPV represented between 5 to 10% of the total installed capacity in the last few years.

China is the global leader in PV deployment, and while BIPV represents only a small fraction of the total, its market has expanded rapidly in recent years, with multi-GW growth projections in the last couple of years. This growth has been supported by national distributed PV regulatory support, as well as regional BIPV-specific incentives. However, China's construction sector downturn since 2022 may limit BIPV development. In India, interest in BIPV has increased in recent years, supported by government initiatives for rooftop solar, with guidelines for BIPV. In the USA, BIPV is largely driven by state-level green building incentives or commercial projects targeting LEED certification. Other countries, like Japan or Korea, have incorporated BIPV into their net-zero building strategies or regional incentive schemes.

Although BIPV solutions have been present in the market for more than two decades now, it still remains a niche market, which hasn't taken off at the same rate as the PV sector as a whole. BIPV has to compete with conventional building materials, that are often cheaper and well known by architects and building owners. Other key barriers include demanding technical requirements and complexity, higher investment cost in comparison to conventional and well established construction materials, involvement of specific and diverse stakeholders (with less experience in PV), need for building-code harmonization, slowdowns in the construction sector of large economies, and challenges integrating with conventional materials and standards. Nevertheless, an increase in building renovation activity in Europe, the rise of emerging markets and favourable policies around Near Zero Energy Buildings (nZEBs) will continue to support the deployment of BIPV solutions.

Unlike standard PV, BIPV supports urban energy autonomy without requiring additional land use, making it a fundamental solution in dense cities where ground-mounted PV fields are neither feasible nor publicly accepted. Notably, Switzerland demonstrates that when BIPV is valued as architecture, adoption increases in recent years has been real.

Manufacturing landscape for BIPV

Europe has over 90 BIPV manufacturers, with the largest number of them found in Italy, Switzerland, Germany, Austria and the Netherlands. These companies generally focus on tailored-made solutions implemented into specific applications and projects. European manufacturers generally operate at small scale (in comparison to conventional PV), with only a few MW of total capacity, with limited annual production, and a strong focus on serving national or regional markets. Although, some companies like Onyx Solar (Spain) stand out, having completed projects worldwide. As a result, while Europe offers a diverse and dynamic manufacturing base, its collective output remains modest.

In contrast, China is rapidly scaling up its BIPV manufacturing capacities with a focus on standardized product formats aimed at large-scale deployment. Manufacturers in China have annual production capacities in the hundreds of MW. This scale allows them to offer products at significantly lower prices than their European counterparts. North America has fewer dedicated BIPV manufacturers, but the industry is still active in both the USA and Canada. However, similarly to Europe, BIPV production remains relatively low volume.

The BIPV industry strongly emphasizes aesthetics and customization. Manufacturers increasingly offer solutions in a variety of colours, finishes, shapes and transparency levels, in order to meet the architectural demands of different building typologies. BIPV applications are diverse, varying in levels of customization, from prefabricated discontinuous roofing solutions to highly customized BIPV façades.

Technology overview and evolution

BIPV becomes a central component of future-proof buildings, offering shade, insulation, daylighting, and visual identity, while avoiding conflicts with zoning or land use, unlike PV farms or visible rooftop modules. Modern BIPV systems are not energy devices applied to buildings, they are building elements that also generate energy.

1. Solarchitecture: www.solarchitecture.ch

DUAL USAGE AND EMERGING PV MARKET SEGMENTS /CONTINUED

The industry's slow pace compared to PV reflects the greater complexity of architectural integration.

Although BIPV remains a niche market compared to the size of the mainstream PV/BAPV market, from a technological perspective it is becoming a relatively mature solution, with a track record of more than 20 years of projects in different countries and building typologies.

The technological evolution of BIPV systems over the past decade has been significant, with a clear focus on meeting key market requirements to enhance adoption by the construction sector. In this regard, building sector needs have required approaching BIPV with a different mindset, where architectural, design and constructive aspects must prevail over electricity generation. For an industry that was born as a specific use case of mainstream PV (which had an undisputed objective of maximizing generation) understanding the needs of a construction sector that was not aligned with that goal has taken time. In the construction sector, characteristics such as aesthetics, customization or transparency play a key role and often remain a priority over generation performance, which is sacrificed for colour, freedom in terms of design or indoor comfort. As the market and industry have matured, BIPV is now understood as a building product with electricity generation being an essential but not unique functionality.

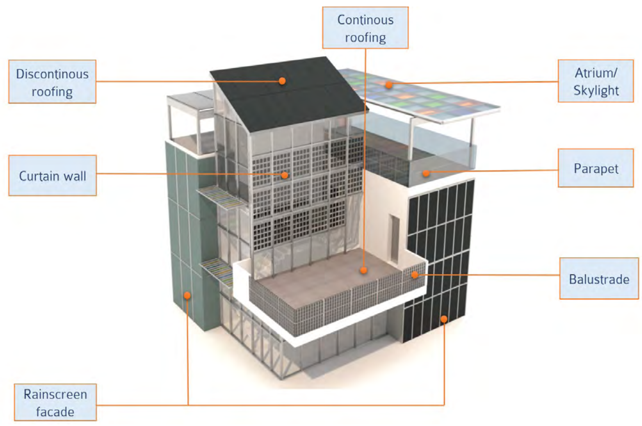
The fragmented nature of BIPV manufacturing is not a weakness, but a reflection of its architectural identity. Unlike standard PV panels, BIPV must meet diverse local codes, aesthetic standards, and construction practices. This variety fosters innovation and aligns with Baukultur values. BIPV is closer to the construction and design industries than the commoditized energy sector, and therefore cannot -and should not-be industrialized in the same way.

The BIPV industry has suffered from the rapid evolution of the general PV cell and module industry trends, going from M2 cells and 4-5 busbars to today's mainstream M10 half-cell and multi-busbar interconnection, in the span of a few years. BIPV manufacturers have had to upgrade equipment more often than expected to adapt to the available cell formats, challenging their industrial business case.

The most prevalent mainstream module solution is currently glass-glass laminate with front and rear glass thicknesses adapted to meet construction requirements and architectural needs. The most common roof and façade solutions generally use 3+3, 4+4 or 6+6 mm glass-glass compositions with EVA or PVB as encapsulant interlayers. Both glasses can be coloured to improve the overall aesthetics. Several types of element and building functionalities can be covered by BIPV as demonstrated in Schema 2.1 (below).. Other solutions such as advanced glazing or photovoltaic accessories (shading systems or canopies) are emerging in the market offering high levels of innovation for the construction industry.

Aesthetics and building functionalities are two of the key requirements from the construction sector, and for the past 10 years improving aesthetics of BIPV modules and technical integration were the most important technological challenge for both research and industrial ecosystems.

SCHEMA 2.1: SOME EXAMPLES OF BIPV SYSTEMS IN A REAL BUILDING CASE



SOURCE: SUPSI

Finding the optimal trade-off between aesthetics, performance and cost is an important goal. The variety of coloured technologies that have emerged are now commercially available (glass serigraphy, selective coatings or coloured encapsulants) giving a range of solutions to improve aesthetics and acceptance from stakeholders[2,3].

BIPV manufacturing relies on flexible and lower automation levels than mainstream PV, and has lower throughputs, to cope with a higher customisation degree in design, especially in façade applications where module size can range from <0.5 m^2 in ventilated facades (using 3+3 mm laminated glass) to up to 8 m^2 in curtain walls application, where the BIPV module can reach up to 4 x 2 m size (using 12+12 mm laminates, double or triple glazing).

Considering the fragmented and diversified building market, without fully automated production and economies of scale BIPV cannot meet the price drops of the mainstream PV industry.

2. Coloured BIPV. Market, research and development, Report IEA-PVPS T15-07: 2019

3. Building Integrated Photovoltaics: A practical handbook for solar buildings' stakeholders, SUPSI, 2024

DUAL USAGE AND EMERGING PV MARKET SEGMENTS /CONTINUED

However, standardisation is possible in certain applications and segments such as roofing tiles/shingles. In Europe, advanced manufacturing for BIPV has been a focus for PV research with H2020 and Horizon Europe calls addressing the challenge. Research projects have tackled advanced flexible manufacturing for different BIPV technologies, including several interconnection technologies (e.g. multi-busbar, back-contact or matrix shingling).

IEA PVPS Task 15 - Creating an enabling framework to accelerate the penetration of BIPV products in the global market of renewables.

Task 15 has recently published a technical guidebook presenting case studies to understand the opportunities and the challenges of BIPV[1].

The ongoing Phase 3 of Task 15 is "Finding a common approach on performance, reliability and safe operation of BIPV systems". There are 5 subtasks that cover market, trends and deployment; pre-normative work on characterisation and performance (for example fire, glare...); developing an IFC-standard for BIPV in open BIM format and creating BIM models for optimal BIPV envelope designs; investigating reliability and long-term behaviour of innovative and coloured BIPV products; training, dissemination to stakeholders and cross sector collaboration

1. Building Integrated Photovoltaics: A technical guidebook. https://doi.org/10.1201/9781003432241

OFF-GRID MARKET DEVELOPMENT

Numbers for off-grid applications are generally not tracked with the same level of accuracy as grid-connected applications, and volumes are marginal compared to the grid-connected market because of the rapid deployment of grid-connected PV and the size of utility-scale-systems. Nevertheless, off-grid applications continue to develop, mainly thanks to rural electrification programs essentially in Asia and Africa but also in South America, and mini-grid development in Africa.

In some countries in Asia and in Africa, off-grid systems with back-up represent an alternative to bringing the grid into remote areas or as an anticipation of grid connection. Two types of off-grid systems can be distinguished:

- Mini-grids, also termed as isolated grids, involve small-scale electricity generation with a capacity between 10 kW and 10 MW. This grid uses one or more renewable energy sources (solar, hydro, wind, biomass) to generate electricity and serves a limited number of consumers in isolation from national electricity transmission networks. Back-up power can be batteries and/or diesel generators.

- Stand-alone systems, for instance solar home systems (SHS) that are not connected to a central power distribution system and supply power for individual appliances, households or small businesses. Batteries are also used to extend the daily duration of energy use.

PV represents a competitive alternative to providing electricity in areas where traditional grids have not yet been deployed. In the same way as mobile phones are connecting people without the traditional lines, PV is leapfrogging complex and costly grid infrastructure, especially to reach the "last miles".

In developing countries (Africa), mini grids are being built to electrify villages and small regions as an alternative to extending costly distribution networks. In some countries, most notably in Australia, as grid infrastructure becomes fragile in the face of extreme climate events (heat waves, fires, floods and storms), micro-grids are being built in edge-of-grid situations to reduce the cost of replacing damaged infrastructure and to provide more resilience for local populations.

Stand-alone systems tend to be specific to countries that have enough solar resources throughout the year to make a PV system viable – either regions where there is demand for low energy applications (lighting, smartphone charging) or more affluent regions with populations seeking self-sufficiency for cultural, environmental or political reasons (USA, Australia, and tourist resorts in isolated environments including islands, mountains and desert regions).

The challenge of providing electricity for lighting and communication, including access to the internet, is being met by PV as one of the most reliable and promising sources of electricity in developing countries. Specific business models are developed (in Africa for instance) and large energy groups are targeting millions of people with such products. Estimated volumes for off grid solar lighting, lanterns and solar home systems by GOGLA[4] affiliates in 2024 grew to 9.3 million units above 2023 volumes but still below 2022 volumes. An estimated 2 million solar pumps, fans and fridges were also installed in 2024. PV has also been deployed to power off-grid agricultural purposes such as water pumping installations.

4. https://www.gogla.org

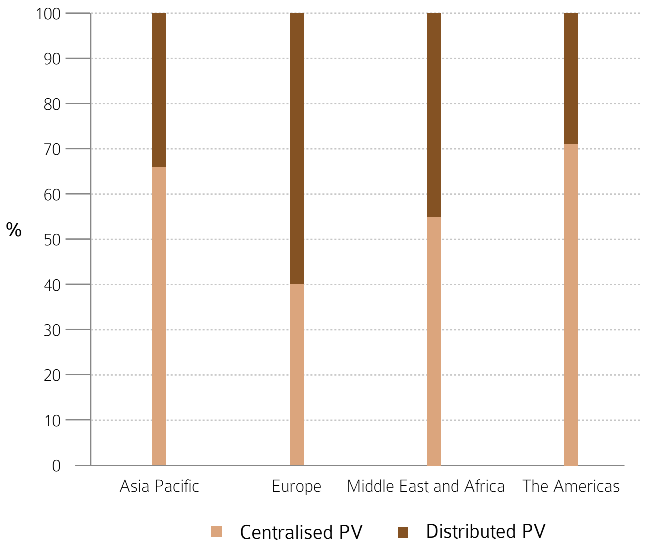
PV DEVELOPMENT PER REGION

The early years of PV development started with the introduction of incentives in Europe, particularly in Germany, and caused a first major market uptake in Europe that peaked in 2008. While the global market size grew slowly in the early 2000s, from around 200 MW in 2000 to around 1 GW in 2004, significant investments in Europe pushed the market faster after this. In 2008, Spain fuelled market development while Europe as a whole accounted for more than 80% of the global market until 2010, with 8 GW in 2006, booming to 17 GW in 2010.

From 2011 onward, the share of Asia and the Americas started to grow rapidly as some European markets contracted in a post-boom "bust" phase (Spain, France) with Asia taking the lead. This evolution has had Asia's share oscillating between 50% and 75% in 2023, reaching nearly 65% in 2024.

Detailed information about most IEA PVPS countries can be found in the yearly National Survey Reports and the Annual Report of the programme. IEA PVPS Task 1 representatives can be contacted for more information about their own individual countries.

FIGURE 2.12: ANNUAL GRID-CONNECTED CENTRALISED AND DISTRIBUTED PV INSTALLATIONS BY REGION IN 2024



*includes off-grid

SOURCE: IEA PVPS & OTHERS

THE AMERICAS

The Americas saw 68.2 GW of PV installed in 2024 for a total cumulative capacity of 316.3 GW in 2024. This represented nearly 14% of annual global capacity, As in 2022 and 2023, most of these capacities are installed in the USA and Brazil, but several countries have annual capacity over the GW level (Chile, Mexico) or continue to install several hundred MW per year (Canada).

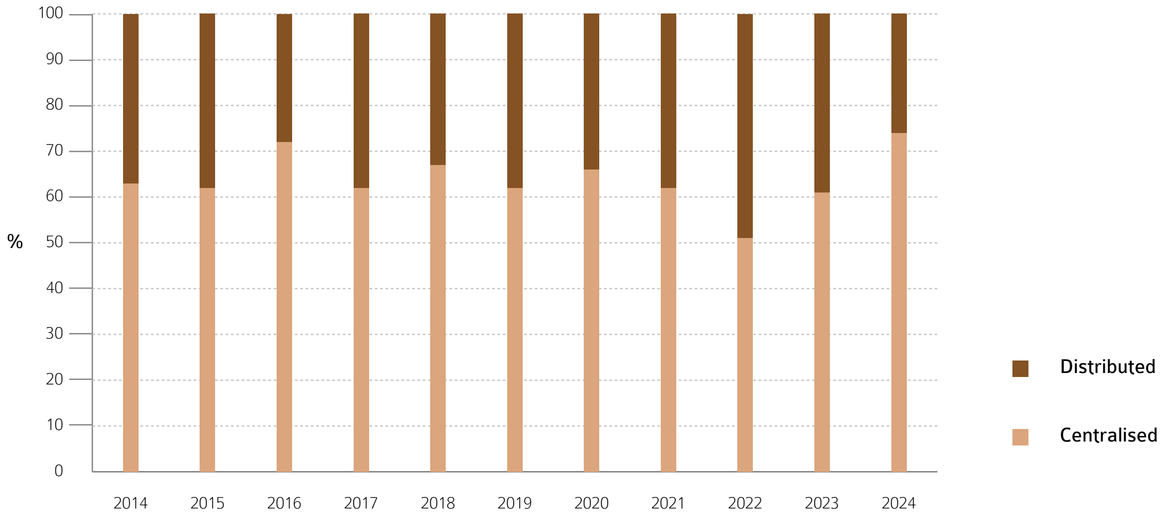
PV is developing in the Americas in both the distributed and centralised segments; the USA is pulled by the utility-scale segment, as is the market in Canada, running both on tenders and PPAs, whilst in Brazil distributed solar is the largest segment. USA has by far the largest installed capacity, adding 47.1 GW to reach a cumulative capacity of 225 GW – 2023 was a record year for solar in the USA, as systems delayed by supply chain issues in 2022 were connected. The momentum continued into 2024, with installations maintaining an upward trend and building on the record growth of the previous year. Utility solar jumped from 24.3 GW in 2023 up to 40.3 GW in 2024, whilst annual distributed solar volumes shrunk to 6.7 GW. The Inflation Reduction Act of 2022 (IRA) incentives also played their part in the growth, as did evolving electricity consumption rates and renewable energy standards and pledges as well as support for solar communities. Evolving quite differently, Brazil continued to be the 2nd market in the Americas and the 6th worldwide, adding 14.3 GW of which 60% (8.7 GW) was in the distributed segment – with over 30 GW of distributed projects having requested grid connection, although it remains to be seen how much of this capacity will be effectively commissioned. Its cumulative capacity is now 52.1 GW.

Mexico added 2.1 GW of new capacity in 2024, evenly shared between centralized (1 GW) and distributed solar (1.1 GW). Chile was the 2nd largest market in South America, heading towards 10 GW cumulative capacity, with more than 1.3 GW commissioned in 2023, across utility, commercial and distributed solar. This growth accelerated in 2024, with 2.1 GW installed to bring cumulative capacity to 11.4 GW. In Colombia, approximately 200 MW of utility-scale PV came online in 2023, with more than 1 GW of projects beginning construction, and over 5 GW of capacity was selected in tenders and there is growing interest in distributed solar for commercial projects. In 2024, installations surged to 1.6 GW, reflecting a significant market expansion.

Other South American markets remain comparably low, but hundreds of MW are still coming online in most countries as smaller centralised system of a few dozen or hundred MW are planned. In Argentina the market is slowly increasing (307 MW in 2024 for over 1.5 GW cumulative capacity) with plans underway for a multi GW system.

PV DEVELOPMENT PER REGION / CONTINUED

FIGURE 2.13: EVOLUTION OF PV INSTALLATIONS IN THE AMERICAS PER SEGMENT



SOURCE: IEA PVPS & OTHERS

ASIA-PACIFIC

The Asia-Pacific region installed 429.7 GW in 2024 and the total installed capacity reached over 1.4 TW. The market remained strong across all of Asia Pacific, with a few exceptions where volumes were down compared to 2023 – for example in Japan. The region represented 71% of global annual capacity, a minor increase up from 69% in 2023, and cumulative capacity in the region has now tipped over the 60% mark.

The size of the Chinese PV market makes it a dominant player in the Asian and global PV markets, while all other markets are lagging behind. Asia is home to several IEA-PVPS GW-scale markets in 2024: China, Japan but also Australia, Korea, with lesser volumes in Malaysia.

China installed 357.3 GWdc (converted from China's National Energy Administration AC figures using the IEA-PVPS AC/DC conversion ratio as explained in this report), reaching a cumulative capacity of 1.04 TWdc. After two years of balanced growth in the distributed and centralised segments, 2023 and 2024 saw a real pull from the centralised segment (65% of new capacity). 2023 was declared a "pivotal year for deployment of renewables" by the National Energy Agency, with the annual target of 160 GW well and truly met. Volumes were spread unevenly across the country, with the highest concentration. in the western provinces of Xianjing and Inner Mongolia, and the provinces around Beijing and north of Shanghai.

Within the IEA-PVPS network, one of the largest markets in terms of installations and potential is India. Given the population of the country, its potential is on a level with China, (or more, given the need for electrification). After a slow 2020 at just 4.4 GW due to a series of administrative issues and difficulties, the market picked up in 2021 (13 GW) and leaped in 2024, adding 31.9 GW of grid connected PV. The annual India market share of utility-scale PV was identical in 2024, 2023 and 2022 at around 75%. GW's of tenders continued to be called in 2024, and many of these were for solar+storage, technology neutral or hybrid systems. The distributed market rose slightly but is still far behind the deployment of utility-scale PV; off grid systems represent considerable volumes of a range of applications. In 2024, annual installed capacity reached 31.9 GW, bringing cumulative installed PV capacity to 124.6 GW.

The market in Japan was down to 5.6 GW for a second year in a row, reaching a cumulative capacity of 97 GW, The Japanese market is slowly contracting year on year, dropping to its lowest annual addition of new capacity since 2012. While the 2nd and 3rd tenders were undersubscribed, the 4th tender in 2024 attracted a larger capacity, surpassing the target, and the average bidding price decreased to 5.06 Yen/kWh from 8.17 Yen/kWh in the 3rd tender. FiT were increased for some segments to encourage building applied systems, and the distributed market remained stable.

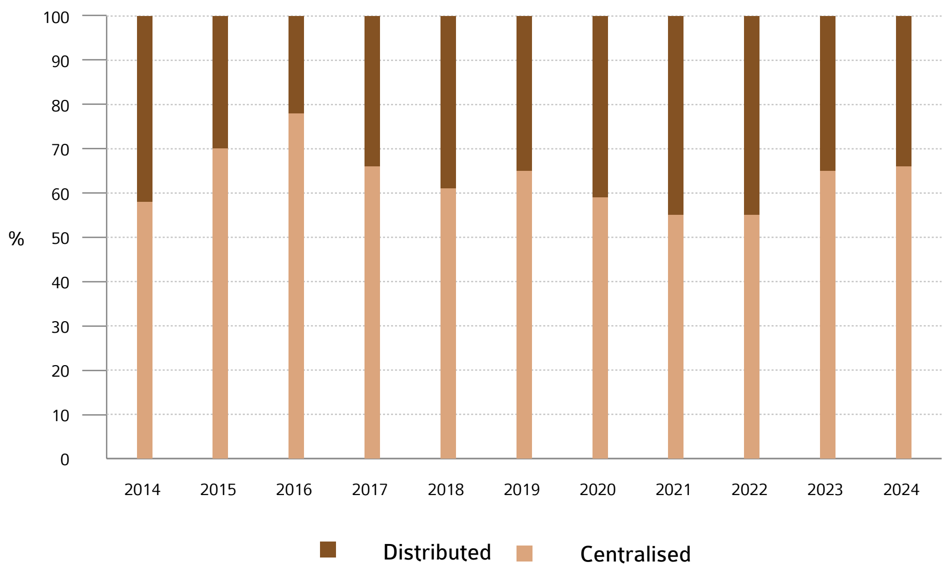
Both Korea and Australia had stable markets; Korea at a steady

PV DEVELOPMENT PER REGION / CONTINUED

2.5 GW (for a cumulative capacity of 30.7 GW) and Australia at 5.3 GW (for a cumulative capacity of 39.8 GW). The two markets are dissimilar though – carried by centralised systems in Korea and the distributed segment in Australia. Australia is investing in new grid capacity to facilitate further development of utility-scale PV as it heads into what is expected to be regular 100% renewable supply over several hours before the end of 2025.

Chinese Taipei added 1.8 GW to reach 14.3 GW, whilst Thailand's market was a standout, adding roughly 3 GW to reach 11.9 GW. Whilst the market in the Philippines remained small in 2023 and 2024, the liberalised energy market has proven attractive for foreign investment and several GW are in the planning stages, whilst construction continued on a 4 GW system - the coming years should see some significant capacity additions. Malaysia added 13 GW for a cumulative 5.4 GW. In Pakistan, large volumes of modules were imported and an estimated 18 GW installed, making Pakistan the 4th market in the world in 2024. These remarkable volumes are the result of low-cost imports allowing consumers and businesses to invest for stable electricity supplies and electricity costs to offset the fragile and expensive electricity supply situation Most of this is decentralised PV, often with some form of storage. Textile manufacturers have begun equipping premises both in Pakistan and Bangladesh to meet their client's climate targets, in what may be the beginning of a new trend in commercial and industrial systems.

FIGURE 2.14: EVOLUTION OF PV INSTALLATIONS IN ASIA PACIFIC PER SEGMENT



SOURCE: IEA PVPS & OTHERS

PV DEVELOPMENT PER REGION / CONTINUED

EUROPE

Europe led the development of PV for many years, adding a large proportion of the world's capacity through the period 2000 to 2012 to reach 70% of cumulative capacity in 2012. The steep price drops from 2009 to 2012, mostly due to the ramping up of Chinese manufacturing capacity, had significant impacts on European markets. Very fast development of PV over short periods of times ("PV booms") led to a demonstrated opposition from many stakeholders from the traditional energy sector, with different mechanisms resulting in declining markets in several countries. From 2013 to 2017, the growth of European PV installations slowed significantly whilst there was rapid growth in the rest of the world, mainly in Asia and the Americas. In addition, several countries implemented measures to decrease the cost of support mechanisms for PV installations by retroactively changing the remuneration levels or by adding taxes. This phenomenon happened mostly in Europe, where the fast development of PV took place before other regions of the world: Spain, Italy, Czech Republic, Belgium, France and others took some measures with a consequent impact on the confidence of financial backers, developers and prosumers.

The situation improved gradually in most countries and PV installations rose in Europe through the early 2020's. Since then, most European markets have grown each year – especially in the distributed segment, pulled by growing adoption of residential, commercial and industrial self-consumption sparked by the high electricity prices of 2022. Annual capacity additions across Europe reached 73.4 GW, up in absolute value from 2023, but slipping 12% of the global market. The cumulative capacity in Europe is now 398.7 GW.

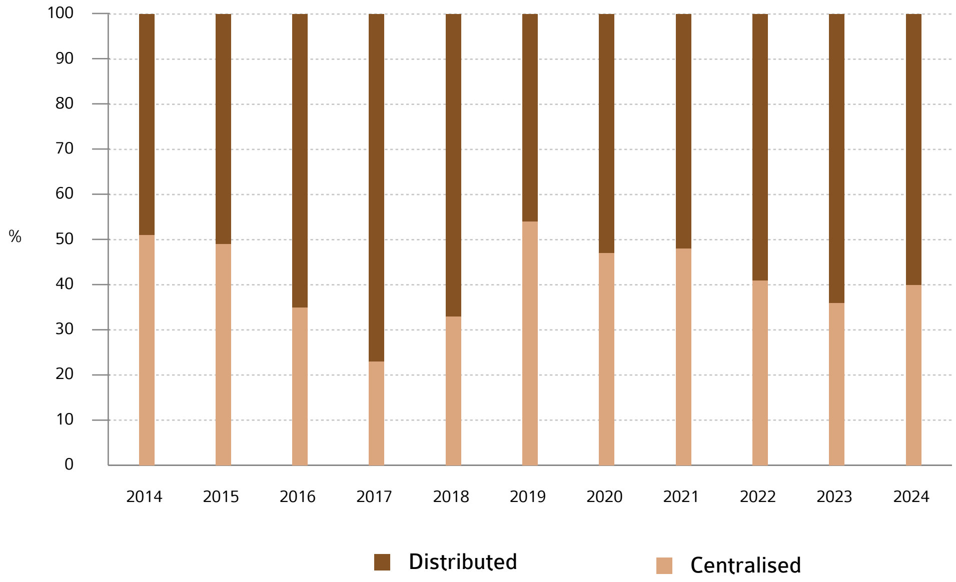
It is important to distinguish the European Union and its countries, which benefit from a common regulatory framework for part of the energy market, and other European countries which have their own energy regulations and are not part of the European Union.

Whilst most European countries used Feed-in Tariff schemes to start developing PV, the movement to self-consumption (or variants) for distributed PV is accelerating while tenders and PPA's became the standard for utility-scale PV. These trends are not unique to Europe, but self-consumption developed faster here than in other locations, no doubt due to the high electricity consumption prices. The development of collective and delocalized self-consumption is also accelerating in EU countries where regulatory frameworks are catching up to market demands.

BIPV has been incentivized in Europe more than in any other part of the world in the past but remains a niche market after several GW of installations. Simplified BIPV seems to develop well in some countries and is likely to increase, always as a niche market, with a slow deployment by different countries of mandatory solar of some sort in building regulations as a response to ambitious climate targets. Merchant utility-scale PV developed in Spain, Germany and France initially with more recent projects in Romania, - and could take a significant market share in a near future, along with PPA and corporate PPA's whose market shares continue to grow. In general, PV development in Europe continued to be dynamic in 2024 as China's manufacturing overcapacity is targeting the more open European market, rather than the USA and India.

PV DEVELOPMENT PER REGION / CONTINUED

FIGURE 2.15: EVOLUTION OF PV INSTALLATIONS IN EUROPE PER SEGMENT



SOURCE: IEA PVPS & OTHERS

EUROPEAN UNION

At the end of 2024, the total installed PV power capacity in the European Union had reached 354 GW, or 90% of the capacity in Europe. As in the wider European market, residential, commercial and industrial rooftops are the most important segment, with 58% of new capacity additions. The market in 2024 was still partially influenced by the remnants of the electricity market price spikes of late 2022 as well as by the aggressive pricing of modules as manufacturing capacity in China increased significantly. Thirteen countries installed more than 1 GW, with Germany heading the list (17.2 GW), followed by Spain (8.7 GW), Italy (6.7 GW), France (6.0 GW), Poland (4.2 GW), the Netherlands (3.4 GW), Greece (2.6 GW), Austria (2.5 GW). The UK, Romania, Portugal, Hungary and Ireland installed between 1 GW and 2 GW of new capacity. Sweden, Belgium and the Czech Republic Market installed just below 1 GW. The split between centralised and distributed generation varies from country to country. The European markets with more than 0.5 GW centralised PV where utility-scale PV is a market driver are Spain, the Netherlands, Hungary and Bulgaria; on the opposite end, more than a dozen countries with over 0.5 GW of new distributed capacity were driven by the distributed market – most notably, Germany, Italy, Poland, France and Austria.

The Netherlands continued to lead in terms of installed capacity per capita in the EU with 1 486 Wp. The number of EU countries that had a penetration rate above the European Union average, now 639 Wp/capita, remained significant – with five above 900 Wp per capita: Netherlands (1 486 Wp), Germany (1 203 Wp), Belgium (982 Wp), Austria (970 Wp), Estonia (965 Wp), Greece (938 Wp), Spain (935 Wp) and an additional several countries above the EU average, including Denmark (886 Wp), Hungary (739 Wp), and others.

OTHER EUROPEAN COUNTRIES

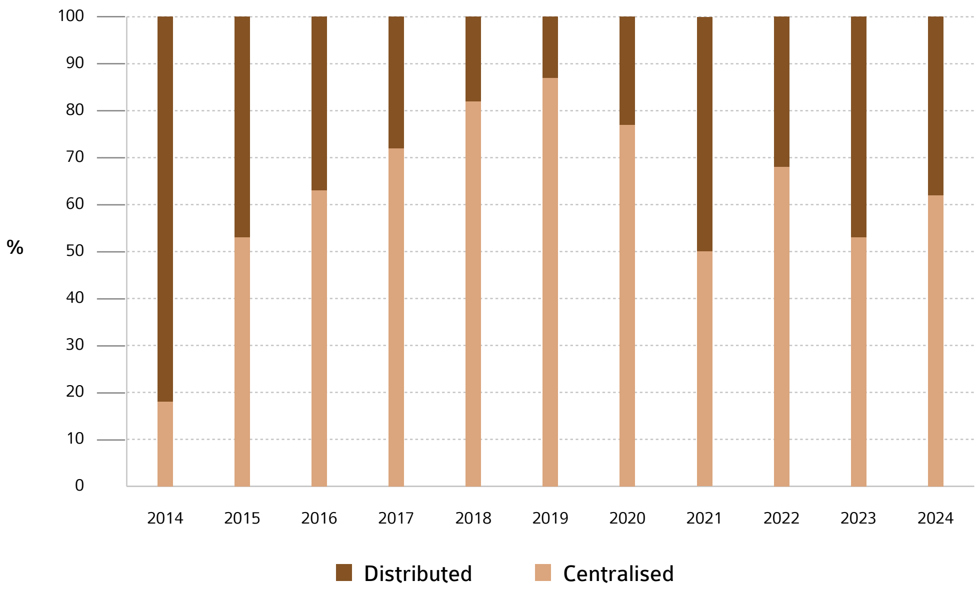
Now part of the IEA-PVPS network, the UK was a growth market with 1.9 GW in 2024, a 50% increase compared to the 2023 value. The country had 17.9 GW of PV at the end of the year 2024 and awarded a record 3.3 GW of CfD tenders, whilst 2022 tender winners are expected to come online through 2025 to 2028, pushing the utility segment to the front. Switzerland continued to expand with 1.8 GW installed, once again, almost all rooftop systems. Türkiye reached a cumulative capacity of 21.5 GW and installed 4.2 GW in 2024.

MIDDLE EAST AND AFRICA

In Middle East and Africa countries, the development of PV remains modest compared to the larger markets, especially in the African countries. However, almost all countries saw a small development of PV in the last years and some of them a significant increase. There is a clear trend in most countries to include PV in energy planning, to set national targets and to prepare the regulatory framework to accommodate PV.

PV DEVELOPMENT PER REGION / CONTINUED

FIGURE 2.16: EVOLUTION OF PV INSTALLATIONS IN AFRICA AND THE MIDDLE EAST PER SEGMENT



SOURCE: IEA PVPS & OTHERS

MIDDLE EAST

With high irradiation, the Middle East is amongst one of the most competitive places for PV installations, with PPAs granted through tendering processes among the lowest in the world, building on excellent irradiation levels. The regional total additions were above 6 GW in 2024 for a cumulative installed capacity of 21.5 GW. In the region most additions were made in Saudi Arabia (3.7 GW) for a cumulative total of 6.7 GW. The UAE added around 500 MW, and Israel contributed 900 MW, reflecting steady market activity.

In the region, energy prices are often supported by government spending, which limited the ability of PV to compete for years, however, countries such as Iran, Qatar, Kuwait, Saudi Arabia, Bahrain, Jordan, Oman and the United Arab Emirates have or are defining targets for renewable and solar energy for the coming years. Conditions are slowly changing for distributed PV, with net-metering being proposed in some countries such as Egypt, Dubai (UAE – where the upper limit was lowered in 2023), Bahrain, Jordan (transitioning to net billing in 2024), and FiT or other mechanisms in Iran, Israel, Saudi Arabia, Tunisia, with plans to introduce similar schemes in Qatar, and Morocco. The UAE is facilitating the connection of distributed generation to the network to help relieve peak loads. Another trend in the fast-developing region is the willingness for governments to develop brand new cities or neighbourhoods, which aim at becoming showcases of renewable energies. This was the case for Masdar City (UAE) or Spark and Neom (Saudi Arabia).

For centralised PV, tenders are an integral part of the plans for PV development in the short and long term in the region, with government and state-owned organisations tendering for single site or multi-site projects as procurement exercises. Examples include Saudi Arabia (3.0 GW in the 6th round of its NREP). Tunisia called tenders for 200 MW in October 2024. Projects for solar-powered green ammonia or hydrogen are underway in Jordan, Egypt, Saudi Arabia, and Morocco, with the UAE pursuing green hydrogen initiatives to decarbonize heavy industries such as steel. Egypt and Morocco are developing large-scale green ammonia plants, while Jordan is advancing a 530 MW solar-powered ammonia project near Aqaba.

AFRICA

The African market is dynamic but difficult to follow, with market reports diverging in terms of capacity, depending on their sources. On top of weak reporting standards and capabilities in many African countries, probably significant volumes of off grid micro and small-scale PV seem to be unreported to authorities. COVID impacted growth in Africa, and the shrunken market from 2019 to 2021 resulted in a break in the previous positive trend of PV development and rural electrification, as fiscal resources were diverted to food and primary necessities.

PV DEVELOPMENT PER REGION / CONTINUED

Africa is by far the smallest regional market, with just an estimated 19.2 GW of cumulative capacity installed, of which over 2.6 GW was installed in 2024. South Africa is the largest market, with 1.2 GW of new capacity in 2024 a slow down compared to 2023 - to reach a cumulative capacity of 8.7 GW. Centralised projects under development include those in the Ivory Coast (agreement for 50 MW), Botswana (100 MW with a PPA signed), Namibia (100 MW), and those under construction Mali (200 MW), South Africa (120 MW) whilst commissioning include a 23 MW system in Gambia. Zambia and Togo have utility scale projects that integrate storage.

Large-scale systems remain a main contributor, but the commercial and industrial segment is slowly gaining momentum and maturity as companies seek to hedge against future rises in electricity prices by generating their own power. Large scale systems for low-carbon hydrogen projects are underway or under discussion, primarily looking to produce ammonia for fertiliser, both strengthening Africa's food security and taking advantage of the excellent irradiation available in many African countries.

Experts are confident that the production of highly competitive H_2 can be reached.

The question of African power infrastructure and markets is essential since many countries have a small, centralized power demand, sometimes below 500 MW. In this respect, the question is not only to connect PV to the grid but also to reinforce the electricity grid infrastructure and interconnection with neighbouring countries.

Mini-grids are an important tool for rural electrification, and a series of projects were commissioned in 2024 including in Nigeria and Zimbabwe. This segment is still very dependent on grants and subsidies while it tries to identify solutions that will lead to pure commercial bankability.

One of the main difficulties for these segments is attracting private investment (with investors wary of the risk levels and upfront cost). However, new renewable energy markets are showing greater appeal to international and local investors - and the most competitive segment for the development of solar in Africa, especially in remote areas i.e. PV plants to replace or complement existing diesel generators, is of interest to investors.

Early solar PV development was supported by government and donor-supported rural electrification with micro and small systems, but the transition to a more market-based development can now be observed. Pay-as-you-go models are used to bypass financing difficulties for residential consumers whilst different pricing formats exist to foster access to clean and reliable electricity. Off-grid PV applications, such as water pumping, are expected to play a growing role in bringing affordable power to consumers.

Support policies and facilitating regulation are more than ever necessary to accelerate uptake ahead of the expected increase in energy consumption and electricity access due to a multitude of factors including population growth and socioeconomic dynamics (increases in the energy consumption per capita for those countries with high electrification rates), decarbonisation of electricity production, electrification of industry and transport, production of green hydrogen...

Africa is already facing severe climate change consequences including water stress and reduced food production, so emerging dual usages such as agrivoltaics and floating PV are potential tools to increase food resources and protect water resources whilst producing electricity.

PV DEVELOPMENT PER REGION / CONTINUED

TABLE 2.6: 2024 PV MARKETS STATISTICS IN DETAIL

COUNTRY	2024 ANNUAL CAPACITY (MW)			2024 CUMULATIVE CAPACITY (MW)		
	DISTRIBUTED	CENTRALISED	TOTAL	DISTRIBUTED	CENTRALISED	TOTAL
AUSTRALIA	3249	2040	5289	26414	13396	39810
AUSTRIA	2183	326	2509	8014	889	8903
BELGIUM	978	0	978	11378	285	11663
CANADA	150	171	321	2422	5174	7597
CHINA	118180	239085	357265	374210	674298	1048508
DENMARK	278	430	708	3271	2022	5293
FINLAND	188	57	245	1142	107	1249
FRANCE	4139	1871	6010	16847	12832	29679
GERMANY	10730	6490	17220	73939	26485	100424
INDIA	7978	23932	31910	23750	100805	124555
ISRAEL	900	0	900	4559	1999	6558
ITALY	4436	2246	6682	25446	11574	37020
JAPAN	3323	2297	5620	57893	39147	97037
KOREA	500	2000	2500	4335	26323	30658
MALAYSIA	436	873	1309	1792	3583	5429
MOROCCO	693	35	728	2372	70	2442
NETHERLANDS	1700	1700	3400	11289	15448	26737
NORWAY	158	8	166	810	12	822
PORTUGAL	679	797	1476	2611	2758	5369
SOUTH AFRICA	618	618	1235	5822	2916	8738
SPAIN	1418	7247	8665	9764	38588	48353
SWEDEN	771	163	934	4657	417	5073
SWITZERLAND	1798	0	1798	8104	68	8172
THAILAND	1500	1500	3000	3650	8226	11875
TÜRKIYE	3319	830	4149	17101	4401	21502
UK	953	953	1906	8348	9541	17889
USA	6744	40333	47077	66928	158088	225015
IEA PVPS	**177999**	**336001**	**514000**	**776865**	**1159453**	**1936370**
BRAZIL	8659	5661	14320	34989	17148	52137
NON IEA PVPS	**50108**	**37019**	**87127**	**183929**	**140672**	**324549**
TOTAL	**228107**	**373020**	**601127**	**960794**	**1300125**	**2260919**

SOURCE: IEA PVPS 8 OTHERS

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POLICY SUPPORT FRAMEWORKS

The policy framework surrounding PV englobes direct and indirect support mechanisms, market regulations, and industrialisation policies.

From the late 90's onwards, the development of PV was pushed by various support mechanisms – from feed-in tariffs, direct subsidies, and tax credits to competitive calls for tender and feed-in premiums. Originally to compensate for the lack of competitivity by reducing the gap between the cost of electr++icity from PV and the cost of electricity from conventional sources, more recent support mechanisms tend to guide PV deployment towards priority segments and applications, as the rapid reduction in PV costs has meant that competitiveness is no longer a problem in many countries (for more detail, see Chapter 6, competitiveness of PV electricity).

Support mechanisms for centralized PV are generally additional to market remuneration, especially in countries with well-established markets with competitive tenders operating as guarantees for a minimal remuneration (Feed in Premiums or Contract for difference remuneration on top of remuneration from sales to consumers, utilities or electricity markets). Power purchase agreements (PPA) and market sales (merchant PV) allow the development outside of support mechanisms.

In new markets, support for distributed PV often begins with net metering, before setting feed-in tariffs, and finally ends in some form of net billing where excess electricity after self-consumption is bought at a utility or government-set rate; this rate can be lower than wholesale electricity costs (to discourage excess) or benefit from feed-in tariffs at premium rates. Direct subsidies and tax credits remain present across the world, although direct subsidy policies tend to be fragile due to their high upfront costs for governments – and are generally reserved for stimulating specific market segments.

For residential and commercial markets, in many countries self-consumption has become the model of choice with regulations and support measures being adapted to accommodate this. Whilst in some competitive markets support mechanisms have been stopped or adapted to encourage emerging segments such as building Integrated PV or AgriPV, climate imperatives, the search for energy sovereignty, and ambitious PV development goals mean that other countries are maintaining strong support schemes. Many different indirect policies to encourage or facilitate PV such as mandatory solar on buildings and car parks and support mechanisms addressing permitting complexity and costs, facilitated access to electricity markets, or grid access policies for prosumers are being used across the world to accelerate PV deployment. Where complete competitivity is not yet present, or market volatility is high, support schemes are evolving according to market maturity, and investor confidence.

Where market volumes are strong, a large part of new policies are focused on self-consumption schemes, citizen communities, and innovative forms of collective and delocalised self-consumption. Policies supporting self-consumption might be considered as non-financial incentives since they set up the regulatory environment to allow consumers to become prosumers or an energy community.

Tools and frameworks to improve the social acceptability of PV are being deployed in many regions; these address factors from local participation in environmental permitting procedures to citizen and First Nations investment in large scale deployments. National policy frameworks in Australia, Canada and the USA have been developed to incorporate PV into First Nations reconciliation and development programs. These frameworks prioritize participation in equity, energy sovereignty, and co-design. Programs include the Indigenous Loan Guarantee Program (Canda) and the First Nations Clean Energy Strategy (Australia). There is a growing recognition that land access and consent are inseparable from clean energy development, reflecting a broader move toward embedding social justice within the global energy transition.

The electrification of usages is an important factor in the energy transition, and the sale of battery storage, heat pumps and EV sales continue to increase for residential and commercial users, whilst big batteries are enabling fast transitions in areas with high penetration rates of renewable energies and increasingly saturated grids. In parallel, the development of "green" hydrogen projects powered by solar and other renewable electricity continues stronger than before as the fragility of gas supply pushes governments to accelerate support for alternatives.

Taxes and the financing of distribution and transmission grids are still key subjects, as deployment of photovoltaics is hindered in some countries due to long wait times for grid upgrades.

The question of market drivers is a complex one since the market is always driven by a combination of several regulations and incentives; in the past public policy and support mechanisms have been the principal driver across the world, however as competitivity is reached, market and consumer forces are increasingly driving PV deployment. The policies, contracts and motivations driving PV deployment are detailed below,

PUBLIC POLICY DRIVERS AND SUPPORT SCHEMES

ACCESS TO SUPPORT MECHANISMS AND REMUNERATION MODELS.

Access to support mechanisms can be through open-access schemes (either unlimited or capped in volume or time, generally with a series of mandatory requirements relating to system size or installation type, sometimes associated with minimal installer qualifications or product certification) or through competitive tenders. Remuneration models tend to include feed-in tariffs (FiT) or premiums (FiP) – sometimes for all the electricity generated from a system, sometimes for excess generation after self-consumption (net billing), green certificates or direct subsidies in open access schemes, whilst tenders are seeing a shift away from feed in tariffs to feed-in premiums and contracts for difference (CfD) – but also to tenders for electricity or generation capacity procurement. Power purchase agreements between generators and consumers can be modelled on any of these mechanisms.

FEED-IN TARIFFS AND PREMIUSA IN OPEN ACCESS SCHEMES

Predefined feed-in tariffs were for a long time an important tool for ensuring roll-out of PV in the distributed segment, and whilst some schemes continued through 2024, many others have been discontinued in the past years. Feed-in tariffs work on a simple principle – electricity produced by the PV system and injected into the grid is paid at a predefined price and guaranteed during a fixed period (often 10 or 20 years). FiT are paid in general by official bodies or utilities and were set-up to stimulate local PV market segments. Generally, only available for small or small to medium-sized systems, the FiT can be fixed over the contract period, or be indexed to inflation or some other indicator, and it can be made available for systems that inject the entirety of their electricity into the grid or, increasingly, only the excess after self-consumption (also called net billing). In some countries, system owners may be able to choose between total injection or the injection of excess after self-consumption and may even be allowed to migrate from one model to another. FiT have demonstrated their efficiency as drivers for the development of residential markets and remain a tool for incentivising self-consumption by managing excess generation without batteries.

Amongst the IEA PVPS member countries that had a government (national, federal or state) mandated open access FiT scheme in 2024, most covered the residential sector, (Austria, China, France, Germany, Israel, Japan, Switzerland, USA), sometimes extending to the commercial and industrial segments (Austria, France, Germany, Israel, Japan, Switzerland). With increased competitiveness, a few countries have or are phasing out government-based FiT schemes (Australia, where utilities set net billing feed-in tariffs as part of their customer acquisition and loyalty strategies, some states have set minimum rates). In Italy agrivoltaic systems can access a specific FiT only available to this segment.

Increasingly countries are either dropping FiT (in 2023, Korea, in 2024 France for some segments, in 2025 China) or reserving them for excess injections after self-consumption (net billing FiT) as grid parity is reached. Depending on the country specifics, FiT can be defined at the national level and at the regional, county or city level (Australia, China, USA etc.) with some regions opting for it and others not, or with different characteristics. FiT can also be granted by utilities themselves (Australia, USA, China (Hong Kong), outside of the policy framework to increase customer fidelity.

PUBLIC POLICY DRIVERS AND SUPPORT SCHEMES / CONTINUED

Feed-in premiums (FiP) are premiums paid on top of the wholesale electricity market price. Fixed and variable premiums can be considered. Israel, use FiP for smaller systems; Sweden and Austria are using a fixed FiP for small decentralized systems – in the case of Sweden, it is managed through tax credits per kWh generated and will be phased out by 2026.

Defining FiT or FiP levels that adequately incentivise PV without overcompensating can be a delicate task, particularly when costs are volatile or subject to steep declines. Entities bearing the cost of FiTs (governments or utilities) will generally seek adjustment mechanisms to ensure that market booms do not lead to cost blowouts and/or over-compensation, a lesson learned from past market booms that occurred in countries such as Spain in 2008, France in 2009, Czech Republic in 2010, Italy in 2011, Belgium in 2012, to a certain extent in China in 2015, 2016 and 2017, and to a lesser extent to other countries. These booms strained budgets and negatively affected the public perception of PV, and most of these markets took years to recover and reexperience growth.

To keep market development stable or financially viable for cost bearers, adjustment mechanisms can include periodic industry negotiations, inflation, and market growth indexation.

Many countries adopted the principle of decreasing FiT levels over time or introduced limited budgets, building on the experience of a consistently reducing price curve for PV systems. In Germany, the FiT level decreases by 1% every 6 months since January 2024. In Japan Fit are adjusted regularly but were steady across 2024 for most systems, but dropped in 2025. In France, the FiT decrease is dependent on both installation rates and economic indicators. The economic indicators and government intervention also allow for increased or decreased FiT if economic conditions (such as cost increases or booming investment) require it.

INCENTIVIZED SELF-CONSUMPTION

Self-consumption, supported by different mechanisms such as net-metering, net-billing, premiums on self-consumed electricity or investment subsidies is becoming the norm in an increasing number of countries. Various forms of support schemes for self-consumption exist, from the historically deployed “net metering” used to develop the market of small-scale PV installations on buildings that were adopted in a large number of countries, although with different definitions of what, precisely, net metering meant (the same vocabulary can imply different regulations and different remuneration models. The best example is in the USA, with the wording “net-metering” being used for different self-consumption schemes in different states).

Incentives both direct and indirect remain essential for the development of self-consumption in many countries. Even where PV is economically competitive, up-front investment costs may deter adoption. To address this, governments and utilities offer remuneration mechanisms for excess electricity.

Remuneration for excess electricity can take one of several forms:

- **Net metering**, where surplus generation offsets consumption over a fixed time window (monthly, quarterly, annually),
- **Net billing**, where exports are sold at wholesale, regulated or contractual prices on short time intervals (5 minutes to 24 hours),
- **Green certificate schemes,** allowing environmental attributes of solar generation to be monetized.

Net-metering has previously supported market development in Belgium, Canada, Denmark, the Netherlands, Portugal, Korea, the USA, Greece, Hungary, and even Pakistan but such policies continue being replaced by net billing, self-consumption policies encouraging real-time consumption of PV electricity (Greece, except for local authorities and households in poverty). Net metering schemes continue to remain in place across countries in South America (Argentina, Brazil, Chile, Mexico...)

Net billing can be incentivised with a feed-in tariff (or feed-in premium added on top of the spot price) for the excess PV electricity fed into the grid. This is for example the case in France, Italy, Japan, Chile, Greece. It can also be associated with time of use rates or low rates to discourage sending excess electricity to the grid, for example encouraging investment in battery storage (Australia and California (USA), Japan). As grids in some parts of the world become more congested, or as distributed solar outpaces consumption, curtailment policies are put in place that no longer guarantee access to the network at all times (Australia, Korea).

Although net-metering is being replaced in some markets (Indonesia, Jordan in 2024, Netherlands by 2027), other countries with emerging PV markets are still maintaining or introducing net-metering (mostly for residential PV) – this is particularly the case in Latin America (Ecuador, Puerto Rico), the Middle East and Africa (Zambia, Kenya, Jordan, UAE (Dubai), Morocco, Tunisia) and Asia (Malaysia, Philippines, and Vietnam, that plans to introduce net metering for small excesses below 10% of generation). While self-consumption and net-metering schemes are based on an energy compensation of electricity flows, other systems exist. Italy attributes different prices to consumed electricity and the electricity fed into the grid.

PUBLIC POLICY DRIVERS AND SUPPORT SCHEMES / CONTINUED

DIRECT SUBSIDIES, REBATES AND TAX BREAKS

PV is characterized by limited maintenance costs, no fuel costs but (relatively) high upfront investment. Direct subsidies were implemented in the early phase of PV development in countries such as Austria, Australia, Finland, Italy, Japan, Korea, Lithuania, Norway, and Sweden just to mention a few – their goal was generally to balance these high investment costs and facilitate investment and/or financing. Whilst direct subsidies remain in place in some areas, they tend to cover only a part of the total installation cost and be reserved for specific segments (residential, low income earners) or applications (agrivoltaics, BIPV).

Incentives can be granted by a wide variety of authorities or sometimes by utilities themselves. They can be unique or add up to each other. Their lifetime is generally quite short, with frequent policy changes, at least to adapt the financial parameters to current project economics and political priorities. Next to central governments, regional states or provinces can propose either the main incentive or additional ones. Those municipalities are involved in renewable energy development and can offer additional advantages. In some cases, utilities are proposing specific deployment schemes to their own customers, generally in the absence of national or local incentives, but sometimes to complement them or to facilitate reaching Renewable Portfolio Standards, where they exist.

Direct subsidies have, for the most part, not demonstrated their ability to support and accelerate PV development over the long term and as tools for the massification of PV are progressively replaced by FiTs, FiPs or other incentives as the significant drop in cost over the past years have made them less necessary for typical PV systems. However, because of the psychological attractiveness of direct upfront subsidies for the residential sector (depending on local culture they can be more attractive to end users than deferred payments through FiT), some countries have continued to use direct subsidies.

Direct subsidies will often be reserved for specific applications, segments or accessories that are not yet competitive, or for users that may not be able to invest otherwise. Examples include subsidies for residential systems (Norway, Switzerland (minimum size increased to 5 kWp in 2024), for agrivoltaic systems (Austria, Japan, Finland), for BIPV systems (Korea), battery storage with/without solar systems (Austria, Australia, Germany, Japan, Spain, Greece, Poland), for systems in high altitude or with higher winter generation than summer (Switzerland), for self-consumption systems (France) for low-income households (Australia, Italy, India, UK, USA...) for PV on public buildings (Japan, Korea, some states in the USA, California, New York, Nevada, Illinois, etc) or for a combination of these such as BIPV on public buildings (Italy).

In the USA the landmark Inflation Reduction Act also included increases to grant programs targeting both rural deployment and deployment in indigenous communities, as well as creating several new grant programs incentivizing deployment in historically marginalized communities, however many of these decisions could be cut back, rescinded or only be available for shorter periods, depending on the results of proposed changes in 2025.

Tax credits have been used for a long time around the world, either on their own or associated with FiT, direct subsidies or rebates. (as early as 2005 in France, USA), and spread to a large variety of countries, ranging from Belgium and Canada to Japan and others. Tax credits can be applied to equipment costs, labour costs or, more rarely, even electricity (Sweden – phased out in 2025).

Tax credits can be open to individuals (USA, Italy, Finland, Spain, Sweden) or commercial entities (USA, Sweden (limited to small systems)), and operate on a yearly or multi-year basis. Tax credits remain a popular tool that is relatively easy to adjust (for example in the USA in 2022 as part of the Inflation Reduction Act). Storage installed with or added to existing PV can also be eligible for tax credits (USA, Austria and Sweden). Occasionally, tax incentives can be increased for low-income households (USA, UK) or limited to self-consumption systems (Spain), and for specific requirements such as local module production (Italy, USA).

Elsewhere, exemption from import duties for PV modules can also stimulate markets with little or no local manufacturing (Armenia, Benin, Mali, Nigeria, Pakistan, Uganda, amongst others).

COMPETITIVE TENDERS

Competitive tenders are used to control the volume, budget, location, type and provenance of equipment of photovoltaic systems that could benefit from support mechanisms. Competitive tenders have been adopted in many countries around the world, with the clear aim of increasing the competitiveness of PV electricity. They are generally run by state organisations (or less often) by utilities looking to either secure increased supply and security of supply on one hand and reduce supply costs on the other or to meet government renewable portfolio standards. This section discusses competitive tenders in which projects compete for access to support mechanisms, not tenders for single-site systems (equivalent to procurement tenders) that are common in countries with small markets, for example in Africa.

In Europe the Netherlands and France were early adopters of competitive tenders, running them as early as 2011/2012. By 2018, uptake was more widespread with roughly 10 countries running tenders (including Germany, Poland), doubling up to at least 20 European countries having trialled or validated tender schemes

PUBLIC POLICY DRIVERS AND SUPPORT SCHEMES / CONTINUED

since then, from Scandinavian countries to the Baltic states down to Mediterranean rim countries. In the past 5 years, large volumes were awarded in tenders in Germany, Italy, Poland, the Netherlands, the UK, Spain and France. Smaller volumes have been awarded in Serbia, Romania, Poland, Ireland, Luxemburg.

The motivation for their use worldwide is increasingly dependent on local conditions in terms of renewable generation targets, land use and local manufacturing concerns. Increasingly, storage is becoming an optional or mandatory part of solar tenders, as grid security and negative electricity market prices impact national frameworks. Tendering can be to give access to support mechanisms, land or electricity procurement contracts. It can also stimulate investment in specific types of systems, for example floating PV or agrivoltaics. A European Commission report "on the performance of support for electricity from renewable sources granted by means of tendering procedures in the Union" published in November 2022 concludes "that introduction of tenders for renewables was a clear success for the European Union" and that they "reduced the support cost significantly compared to administrative schemes, enhanced the deployment of renewable capacities and provided a solid framework for technological improvement".

Initially, the first remuneration models in tenders were feed-in tariffs (FiT) or feed-in premiums (FiP) and whilst they are still used in some countries for utility scale systems, they are often reserved for smaller commercial and industrial (C&I) systems on buildings. Increasingly more common, Contract for Difference (CfD) contracts are replacing FiT ad FiP to allow governments to recover windfall remuneration in times of high markets prices.

Feed in Tariffs are where remuneration is based on a fixed price per kWh, and Feed-in Premiums (FiP) are a fixed premium that is paid on top of the variable electricity wholesale market price, leading to variable remuneration. FiT are awarded in utility scale tenders in Israel, Brazil, India, but reserved for certain segments such as C&I in Japan, Luxembourg, China, Egypt. Japan uses both FiT and FiP in its tenders, depending on system size. In 2023, Austria transitioned their tendered feed-in tariffs to feed in premiums, joining the Netherlands and Germany, who used this mechanism already – although Germany is expected to transition to CfD by 2027. A Contract for Difference scheme (UK, Greece, France, Italy, Hungary, Albania, Romania, Serbia, China, Australia) is a FiP that ensures constant remuneration by covering the difference between the expected remuneration and the electricity market price. Tenders have also been run with some or all of the remuneration based on green certificates (Australia) or investment subsidies (Luxembourg).

INCREASINGLY LARGE VOLUME OF COMPETITIVE TENDERS CALLED ACROSS THE WORLD, INDIA LEADING WITH 15 GW CALLED

In 2024, in the Middle East and North Africa, competitive tenders for utility scale PV were issued in Israel, Tunisia (> 600 MW), Saudi Arabia (3 GW, added to the 2023 3.7 GW) and South Africa (1.8 GW). In North America the USA ran tenders at state or utility levels. In Latin America, Chile, called a public tender in 2024, but this tender was cancelled amidst international concerns on lack of transparency. In Asia, India continued with their tender scheme, calling for 15 GW of solar, and Japan, Korea (1 GW), Malaysia (2 GW) continued their schemes. Australia launched the first round of its Capacity Investment Scheme, awarding 2.7 GW to solar in the first round

The European Commission's revised internal electricity market design states (2024) "The Union legislation on the electricity market design aims to harmonise the design of direct price support schemes in the form of two-way contracts for difference" with the goal of curbing excessive generator revenues in times of volatile electricity markets.

Tenders have mostly been used to frame PV development and PV costs on a national level. This implies defining a maximum capacity and selecting the cheapest suitable plants to develop. However, tenders can be further developed and used to guide towards larger, long-term roadmaps on power capacity and segment development. By planning smartly with transmission grid operators, tenders can allow the development of specific capacities for defined technologies, optimize the grid and anticipate the energy transition as a tool to support local industry. The integration of co-located storage within tender frameworks can facilitate grid operations, increase the value of variable renewable generation such as solar and reduce curtailment by shifting production to periods of high demand. Tender rules can promote storage configurations to match local grid needs, for example short-duration capacity for frequency regulation or long-duration capacity for meeting evening demand peaks. Co-location can also reduce grid investments for system connection by reducing the required connection capacity as export peaks are flattened and reduced.

Competitive tender specifications can also be tools to build public acceptance by setting criteria that satisfy public and social acceptability guidelines – such as reserving support to specific types of land usage.

PUBLIC POLICY DRIVERS AND SUPPORT SCHEMES / CONTINUED

SELECTION CRITERIA

As a tool to control and guide towards the type of PV system deemed desirable, selection criteria or bonuses can either allow projects that are inherently more costly to become competitive with classic projects by giving bonus points in selection criteria or simply eliminate certain types of projects. Other mechanisms that can be used include reserved volumes. These mechanisms are becoming more generalised, building on localised experiences (for example early use of carbon footprints in France).

In 2024, selection criteria was used to encourage or enable projects depending on:

- system size (between two thresholds, as in Korea, France, Poland),
- types of land usages or for being installed on buildings (France, Germany, Romania),
- the presence of storage, (India, Australia, Germany)
- carbon content/footprint (France, Korea),
- local content (Algeria, Türkiye, India, South Africa),
- local equity ie ownership by domestic entities, often but not always linked to standard company ownership rules (Malaysia),
- citizen governance or financing (France, Austria) or participation of indigenous or first nations peoples (Australia),
- the specific application, such as agrivoltaics (Italy) or floating PV (India, Malaysia, Italy in 2025).

Competitive tenders can also be used as a driver for innovation, allowing higher remuneration levels for innovative systems not quite ready for the market, as used in France since 2017 and Germany since 2020.

Environmental or local content constraints are introduced to give an advantage to local companies or to favour a better environmental footprint of the products. Reserved volumes or segment bonuses promote specific technologies or impose additional constraints such as local manufacturing to boost the local industry. A local content parameter can be an additional primary or secondary key in the selection criteria. This type of requirement aims at enabling the development of local solar module manufacturing..

Technology-neutral tenders are increasingly being used as governments tender renewables capacity. In this case, PV is put in competition with other generation sources. Past experiments with mixed auctions based on solar and wind (Canada, France, Germany, Spain and Italy) have tended to demonstrate that solar is most competitive, More recently open tenders with solar, wind and storage eligible in Australia had more balanced results.

EU POLICY FRAMEWORK

The 2019 European Green Deal, an overarching policy roadmap aiming for a clean, circular economy, restoration of biodiversity, pollution reduction, set a commitment to climate neutrality by 2050. In 2020, the European Commission proposed raising the 2030 climate targets to at least 55% GHG reduction compared to 1990 levels. The accompanying impact assessment confirmed that this ambition was both technically and economically feasible, projecting a renewable energy share of approximately 38.5% to meet the target. To operationalise this ambition, the "Fit for 55" package proposed a comprehensive revision of energy and climate legislation. The package underlined the role of solar energy, particularly photovoltaics, as a cornerstone of the EU's decarbonisation and energy security strategies.

Following the energy crisis sparked by Russia's invasion of Ukraine, the EU revisited energy sovereignty with the REPowerEU plan (2022), which reaffirmed the 55% emissions reduction goal and set out to end dependency on Russian fossil fuels well before 2030. It was accompanied by the EUSAolar Energy Strategy, calling for the deployment of over 720 GWp of cumulative solar PV capacity by 2030.

To accelerate this deployment, the EU Solar Strategy established several initiatives:

- European Solar Rooftops Initiative – making rooftop solar mandatory on new public, commercial, and residential buildings (phased by 2026–2029).
- Utility-scale deployment with multi-use land – including agri-PV, floating PV, and PV on transport infrastructure.
- Urban solar planning – integrating PV in buildings, districts, and cities.
- Grid readiness – improving network infrastructure for distributed solar integration.

PUBLIC POLICY DRIVERS AND SUPPORT SCHEMES / CONTINUED

- **Solar value chain resilience – reinforcing EU-based manufacturing and reducing supply chain dependencies.**
- **Investment support – including de-risking instruments and funding to strengthen EU PV industry.**

In June 2024, the EU adopted the Net-Zero Industry Act, aiming to create a conducive environment for scaling up domestic manufacturing of strategic net-zero technologies, including PV. The Act simplifies permitting, supports skills development, and sets a 2030 benchmark for domestically manufactured technologies to meet 40% of the EU's deployment needs, helping bolster PV competitiveness and reduce reliance on imports.

IMPACT OF MARKET CHANGES ON COMPETITIVE TENDERS

Competitive tenders have driven the worldwide market, giving project developers the security of contracts backed by state support mechanisms to invest in increasingly large volumes, and providing governments with a tool to map and control solar energy capacity increases.

Tendered prices in competitive tenders were steadily decreasing up to 2021 when the downward price trend halted due to module price hikes resulting from a combination of COVID and demand impacts, before dropping again from late 2022. Since bidders must compete with one another, they tend to reduce the bidding price to the minimum possible and shrink their margins. Developers with a large number of projects in previous tenders will have good visibility on price pressure and are most likely to be able to price their projects to winning bids.

The past years have demonstrated how low the bids can go under the constraint of competitive tenders. Low bids associated with FiT or CfD remuneration could be risky- many experts believe such low bids are only possible with extremely low capital costs, low component costs and reduced risk hedging. The shrinking profit margins, especially in super-competitive tenders, were and are a threat to the long-term stability of some market actors. Because of strong competition, the most competitive (lowest) bids are also often costed on expected module price drops, leaving these projects fragile and potentially unable to remain economically viable when confronted with rising costs as was the case over 2021/2022. These practices can also be problematic in periods were the costs of one component goes down whilst others increase, as has been seen across 2023 and 2024 as modules prices went down but supporting structures (mounting and racking) and transformers increased in price.

Across all renewable energies, negative prices for tenders with FiP mechanisms have also been seen in the past; in these cases, market sales or PPA's provide the project remunerations whilst the tenders framework provides other required keys such as grid capacity, security for debt financing...

Upper ceilings on tendered prices can be insufficient (either because they are below required remuneration levels or because they are less attractive than market prices). In this last case, for competitive tenders to remain attractive to project developers, they must provide benefits that cannot be found on the market – state backing of long-term contracts is the most obvious advantage, pleasing both equity and debt participants, but also landowners.

The past five years has seen significant volatility in the photovoltaics competitivity landscape – including increasing PV costs in 2020/2021, high electricity market costs in parts of the world in 2022, dropping over 2023 and stabilising in 2024; significant drops in module prices both in 2023 and 2024. As a consequence, the dynamics of project profitability have varied, as has the attractivity of government-run tenders and PPA's. In this context, tenders have been under-subscribed (France, South Africa in 2022, Japan, Korea, Poland, Serbia in 2023) – for example, when market conditions were more attractive - under-awarded when tendered rates were considered uncompetitive i.e. close to or over ceiling rates (France in 2020 and 2021 for some segments, Spain in 2022) or even over-subscribed where the security of investment and low modules costs made them more attractive (in 2023: Argentina, France, Germany, UAE). Oversubscription can also be a sign that the volatility of market conditions has made investors wary, and lead developers to seek remuneration mechanisms with safety nets (Australia).

As competitive tenders become more competitive and selection criteria more specific, project promoters and developers are increasingly working towards greenfield (new) projects with private remuneration contracts, either selling to corporate clients (corporate PPA's) (Europe, North America), or even directly to electricity markets (merchant PV) (Australia, Bulgaria, Croatia, Germany, Romania, Spain, a few projects in Africa (Namibia) – see below.

PUBLIC POLICY DRIVERS AND SUPPORT SCHEMES / CONTINUED

BID PRICES DROPPING AGAIN AFTER 2023 INCREASES.

In 2024 the lowest bids once again decreased, with bids as low as 13 USD/MWh in Saudi Arabia, 19 USD/MWh in Israel and 30 USD/MWh in India. The lowest bid at 30 USD/Wh in Japan in 2024 was in the 20 th round of tenders although the average bid was 45 USD/MWh, down on 2023 average bids of 55 USD/MWh. In Europe, the lowest bid was in Germany at 39 USD/MWh (with an average in this tender of 55 USD/MWh - equivalent to the lowest bids in 2023). In comparison, the lowest bids in France for utility scale systems reached 86 USD/MWh, continuing its place in the highest price range despite its Top 10 annual market volumes.

For those countries with tenders specific to the C&I/building segment, prices were higher, from 75 USD/MWh in Germany (down on 2023 bids) to 110 USD/MWh in France, (up on 2023 bids)

TRADE OF GREEN CERTIFICATES AND SIMILAR SCHEMES

Green certificates and similar schemes based on Renewable Portfolio Standard (RPS) are only used in a few markets, and their use seems to be shrinking, at least for PV. Green certificates with a set value can be issued within the framework of government or state support mechanisms (Belgium (residential systems), Australia, Isreal, Italy, China). They can also be traded at market values between generators and utilities as part of RPS obligations (USA - predominantly but not only utility-scale systems). The regulatory approach commonly referred to as RPS aims at promoting the development of renewable energy sources by imposing a quota of RE sources. The authorities define a share of electricity to be produced by renewable sources that all utilities must adopt, either by producing themselves or by buying specific certificates on the market. When available, these certificates are sometimes called "green certificates" and allow renewable electricity producers to get a variable remuneration for their electricity, based on the market price of these certificates.

Green certificates can also be bought to satisfy voluntary social responsibility goals (in this case, most often Guarantees of Origin (GO) are attached to electricity sold to consumers with a surcharge for the guarantee). Their value can vary depending on the local markets and how active they are, and trading GO's may or may not be cumulative with remuneration from government-financed support mechanisms. In Europe large prices drops occurred from 2023 to 2024, as larger volumes became available. The EU Corporate Sustainability Reporting Directive and the proposed Green Claims Directive are likely to support increased trading of GO; it remains to be seen whether increased demand will impact prices as PV and wind market growth increase supply. In North America, prices were more stable, although there are significant variations between states and regions.

MARKET-DRIVEN PV

Most countries now have PV being developed outside of government backed financial incentive programmes; this includes both sales and remuneration through PPA's, CPPA and merchant PV but also remuneration through "avoided costs" (ie electricity that is not bought because it is generated by the consumer) as PV is increasingly used for self-consumption. Investments can be driven by corporate environmental, social and governance (ESG) strategies, independent power producer (IPP) development roadmaps, or public policy driven Renewable Portfolio Standard (RPS) obligations.

In some areas PV and renewable energy penetration rates have increased to the point that electricity generated from these sources is outstripping demand, leading to voluntary or imposed curtailment on the generation side and negative prices on the market side. Strategies for maintaining market competitiveness are pushing not only technical optimisation of PV systems (siting and orientation choices, grid connection optimisation and voluntary curtailment) but also market optimisations (use of batteries to modify time of sale, revenue stacking ie combining revenue from electricity sales but also the remuneration of services such as capacity reserve, systems services etc).

ENVIRONMENTAL, SOCIAL AND GOVERNANCE (ESG) STRATEGIES

Companies (and utilities and local authorities) are progressively adopting PV as a tool to improve ESG strategies. Investing in PV for self-consumption or buying electricity generated (or Guarantee of Origin certificates) from PV systems can fulfil all three aspects: by generating renewable energy and reducing reliance on and emissions from fossil fuels it supports environmental goals; supporting local job creation or installation companies enhances social impact, and, finally, investing in PV can help to safe-guard against rising electricity prices, demonstrate energy consumption transparency and increase citizen (end-client) confidence in corporate sustainability roadmaps.

In this framework, companies have several routes to integrating PV into their action plans:

MARKET-DRIVEN PV / CONTINUED

1. Trading in Green certificates and Guarantee of Origin (GO) certificates (see above)
2. Non-incentivized self-consumption - investing in PV systems (on or off site) to supply their own consumption and/or participating in energy communities
3. Power Purchase Agreements - Contracting long term supply contracts for greenfield (or even brownfield) PV systems (PPA/CPPA)
4. Merchant PV - Buying PV electricity on the electricity market

NON-INCENTIVIZED SELF-CONSUMPTION

Self-consumption ceases to need incentives when the revenue from the savings on electricity bills (the self-consumed part) and the revenue from the sale of excess PV electricity covers the long-term cost of installing, financing and operating the PV system. As retail and wholesale electricity prices rise and PV LCOE[1] reduces, self-consumption has become an obvious choice in many markets – particularly in European and Australian markets or markets where electricity prices were disrupted due to the Ukraine conflict. However, the return of electricity prices to previous lows can reduce consumer uptake as well (Spain).

Where self-consumption becomes the norm, grid managers can become wary of transfers in the burden of grid costs between consumer/producer categories, or even revenue loss if revenue is proportional to consumption. In this context, fixed fees or self-consumption taxes and penalties can reduce the attractiveness of self-consumption and impact uptake. For example, concerns over such cost-shifting from PV to non-PV customers in the USA were cited as one of the main drivers of changes to California's net energy metering revision in 2022, where grid participation charges and minimum bills were initially considered.

As grid capacity becomes saturated, triggering curtailment and balancing cost increases, consumers are increasingly looking to optimise their investments with solutions such as storage to energy sharing through collective self-consumption or energy communities to improve competitiveness. In Australia, Germany, some states in the USA, China, grid and injection constraints have led to storage becoming a common accessory to new PV installations

1 LCOE – Levelised Cost of Electricty, a mesure of the cost of each kWh that is generated

POWER PURCHASE AGREEMENTS

Power Purchase Agreements (PPAs) are long-term private contracts between a PV producer and one or several off-takers: consumers (Corporate PPA) or electricity resellers (PPA). While FiT (or CfD, in the case of virtual PPA's) are paid in general by official bodies or utilities, commercial PPAs are contracts between the PV plant owner and an off-taker for the electricity produced, over a defined period. Such contracts guarantee a certain level of revenue and are increasingly popular for unsubsidized PV because the cost per kWh is negotiated between the parties. If built on a FiT model, in times of high electricity prices (2021, 2022), the PV buyer has an advantage if the contract was negotiated in times of lower prices. PPAs imply sourcing of solar electricity without necessarily being physically connected to the power plant - a solution favoured more and more by large companies willing to decrease their GHG emissions through corporate PPA's. In the case of virtual PPAS's operating on a CfD, the off- taker pays the generator (or receives from the generator) the difference between the agreed-on price and the price sold on the electricity market sales; in this case, the off-taker carries the risk burden for the generator. Initially deployed in the wind industry, solar PPAs continued robust growth in 2024. Shorter permitting processes and reduced construction timelines explain why solar PPAs have become the preferred choice for corporate energy procurement. Growth was particularly significant in Asia-Pacific, followed by Europe and North America. Solar PPAs were widely adopted by industrial facilities, logistics centres, and retailers. Major off-takers included technology firms, online platforms, and notably, data centres. The European Union incites member states to remove administrative barriers to long-term PPA and to facilitate their adoption. One of the principal barriers to developing PPAs is the multitude of risks, from low production to off-takers insolvency, and there is a small but growing market in risk hedging; Italy introduced a risk mitigation mechanism to support long-term renewable energy PPAs, allowing the government to step in if one party defaults. Hybrid PPAs, combining renewables and storage, are gaining traction, as buyers look for greater supply reliability and flexibility.

In Europe, at least 19 GW of renewables were contracted under PPAs, of which solar projects are the most significant segment. Spain and Germany lead the European PPA market, with Poland, the UK and Greece also holding significant market share. In the USA, the PPA market grew to between 15 GW and 25 GW,, largely driven by data centres, which have almost 60% of contracted capacity. The Asia-Pacific region contracted over 27 GW of corporate PPAs, 10 GW more than in 2023. Australia reached record corporate PV PPA volumes in 2024, led by heavy industry and mining off-takers. In China, nearly all utility-scale PV projects

MARKET-DRIVEN PV / CONTINUED

above 50 MW secured long-term contracts through state-run tenders, with a shift to contracts-for-difference planned from mid-2025. In Japan, corporate and distributed PV PPAs continued to expand, supported by long-term contracts across commercial and industrial sectors. In Korea, PPA uptake remained limited, although regulatory updates in 2024 have aimed to improve market access for corporate buyers and streamline approval processes.

Whilst many PPA developers and buyers are industry specific, there is also a wide range of global energy players present, as discussed in Chapter 4.

MERCHANT PV

Merchant-based PV plants are expected to play a growing role in the development of the PV market. They are PV plants where the business model relies on sales on electricity markets. The design of the electricity market plays an important role in the emergence of this type of business model as the market should provide both short-term and long-term incentives. Whilst several countries experimented with merchant PV as long ago as early 2010 (unsuccessfully in Chile, for example), recently more competitive LCOE and the higher electricity prices on the European market in 2022/early 2023 encouraged project developers to investigate this option more seriously.

Despite macroeconomic pressure from oversupply in module manufacturing and declining prices, merchant capacity increased in 2024. The growth was supported by developers' ability to optimise market-led deployment without subsidy reliance, and analysts expect its share of new PV capacity to continue rising, especially in deregulated or reforming electricity markets that provide both short-term price signals and long-term market visibility.

The merchant model is increasingly adopted across Europe (especially Spain, Germany, Italy, and the Nordics), Asia-Pacific (notably Australia or the Philippines), Africa (with projects in Botswana and Namibia), North America (driven by shorter PPAs in the USA), and the Middle East. In Australia, approximately 18% of its ~20 GW capacity in 2022 was merchant, and this trend continued into early 2024 with further uncontracted capacity being deployed. Developments included licensing of a 60 MW fully merchant solar plant in Namibia, along with the first merchant solar farm in sub Saharan Africa directly trading into the Southern African Power Pool. In the USA, shortening PPA tenures (often under 10 years) have augmented exposure to merchant risk, making sales on spot markets increasingly material to project economics. While the spike in Europe's merchant activity during the electricity-price crisis of 2022 – early 2023 began to moderate as wholesale prices stabilized in late 2023 and 2024, the merchant route remained a core strategy for new capacity. Merchant PV now represents a significant portion of utility-scale additions in markets where price signals are robust, offering both greater flexibility and risk, to developers and financiers alike.

NEGATIVE PRICES AND CURTAILEMENT: POLICY AND MARKET IMPACTS

Curtailment increased markedly in 2024, especially in high-PV-penetration countries. Chile saw a sharp rise, with 5.9 TWh of solar and wind curtailed (121% increase over 2023) as 2.4 GW of new PV was added. Some plants experienced curtailment exceeding 50% annually, especially in the northern regions of Antofagasta and Atacama, where lower consumption and insufficient transmission to the south persist. Germany's solar curtailment nearly doubled and exceeded 13% on peak days, driven by high summer irradiation and limited smart grid coordination. Annual curtailment was low in Spain in 2024, at under 1%, but still represents millions of EUR in lost revenue. Monthly curtailment is expected to be in double digits in some months by 2025.. Cyprus reported a curtailment rate of 29% for all renewables, up from 3.3% in 2022, largely due to constrained grid capacity and uncoordinated residential PV installations (1 500 MWh of residential solar curtailed in 2024).

Negative electricity prices became more frequent in solar-heavy hours. In Spain, negative pricing occurred over more than 650 operating hours, with spot prices reaching as low as -2.0 EUR/ kWh. These conditions were echoed in Austria and Australia, where midday oversupply met limited demand elasticity. In Germany, policy responses included a new "solar peak" law suspending feed-in tariffs when prices go negative, introduced in 2025. Crucially, the law allows those hours to be recovered over a 20-year compensation horizon, incentivising self-consumption and battery deployment without challenging project bankability.

Curtailment policies shifted in 2024 from reactive to preventive. In Germany, new PV installations must include smart meters and comply with dynamic feed-in rules, supporting grid flexibility and reducing unmanaged surpluses. In Australia, while the national network curtailment rate held steady at 1.17%, economic curtailment rose in areas like South Australia. Policy discussions explored solutions such as dynamic load control - reconfiguring off-peak water heaters to absorb excess solar generation. In China, over 20 provinces now mandate energy storage for new wind and solar projects, with some raising the required capacity ratio to 20%. These rules have mitigated grid saturation but increased project costs and revealed low utilisation of mandated storage. Brazil, meanwhile, faces projected curtailment rates of 8% nationally and up to 11% in the northeast by 2035, with regulatory inertia stalling investment in flexible infrastructure.

Voluntary and mandatory curtailment mechanisms increasingly coexist, but policy clarity remains uneven. In Australia and Belgium, curtailment results from both market-driven price signals and grid constraints. Economic curtailment occurs when the regional spot price is so low that generators prefer to not sell; this generally occurs when prices go negative - these price signals often stem from structural transmission bottlenecks, meaning local generation out-stripping consumption cannot be sent to consumption points further away. Spain and Germany have moved to link tariff suspensions and bidding behaviour to real-time grid conditions, while voluntary curtailment is also emerging as a default strategy in merchant projects unable to secure priority dispatch or firm PPAs. Beyond avoiding losses, more active output management is gaining traction, with some projects curtailing during low-price hours to offer up regulation capacity or participate in balancing and ancillary service markets. An increasing number of projects are built with multiple revenue streams, including electricity sales and system services.

Curtailment is also used in some markets for local grid management, and ongoing regulatory processes aim to formalise fair treatment for PV owners. Issues such as volt-watt responses (where smart inverters gradually reduce power exports when network voltage limits are met, generally in the context of generation exceeding consumption locally) highlight the need for equitable curtailment protocols, as edge-of-grid systems will be impacted first and more often. The shift to 15-minute market clearing intervals in some electricity markets could allow more precise targeting of over-generation periods, potentially reducing unnecessary curtailment volumes.

Despite policy progress, major gaps persist in transparency and compensation design. Only a few countries - such as France (notably in overseas territories) and Korea - define compensation eligibility explicitly within curtailment regimes. In many others, curtailment remains uncompensated or only partially remunerated, challenging investment stability. China continues to apply a cap on curtailment targets, but enforcement is inconsistent across provinces. In Brazil, ongoing regulatory delays around energy storage and curtailment thresholds continue to inhibit planning certainty.

In 2024, curtailment became a structural feature of global solar deployment. Where PV now represents a substantial share of midday generation, inflexible grids, static demand, and market rules not yet adapted to high renewables have led to curtailed volumes and negative pricing. However, a transition is underway. Governments are beginning to shift from mitigation to integrated planning, using curtailment not only as a policy signal to accelerate storage, reform tariffs, and enable smarter distributed generation, but also as a tool to unlock new market opportunities. Whether these reforms will be implemented fast enough to support the next wave of PV investments remains an open question.

CONSUMER DRIVEN PV: PROSUMER AND ENERGY COMMUNITY

SELF-CONSUMPTION FRAMEWORKS

Self-consumption regulations have been implemented across the globe, with a dual objective: to empower consumers (residential, commercial and even industrial) to play an active role in the energy transition and to reduce the cost burden of other types of support mechanisms. The rise of self-consumption frameworks can be seen as part of the natural progression from strongly incentivised PV (direct investment subsidies, FiT and FiP) to a more consumer-led development of distributed PV, with frameworks adapted to take into account increasingly higher penetration rates of PV generation in final consumption, the reduction of transmission and distribution costs and the use of integrated energy management systems (electricity, heat, efficiency, storage, etc.).

At its core, self-consumption operates under a common physical principle: the electricity that is produced by the PV system and locally consumed reduces the quantity of electricity on the consumer's bill (ie avoids buying electricity from a supplier). Existing and new self-consumption frameworks are being adapted to manage the growth of distributed PV while balancing the needs of system operators, markets, and consumers.

Self-consumption is legally permitted in many countries, but mechanisms to promote or regulate it differ. Most frameworks address several key regulatory touchpoints:

1. Initial grid connection and/or annual grid access fees,
2. The right to inject excess electricity and receive compensation,
3. Third party ownership of the PV system

Grid connection fees can be reduced or waived to promote self-consumption - especially when consumers are already equipped with electronic meters that require no direct intervention (France, Finland, Netherlands) or on the contrary adapted to cover self-consumption. Because grid fees often include a variable component tied to consumption, alternative approaches have been introduced to stabilize distribution system operator revenues. These include modified tariff structures that increase the fixed portion of bills (Australia, France, Switzerland), specific grid taxes for net-metered or billed electricity (Israel, Spain, Belgium), or minimum bills to guarantee base-level contributions (USA). In federal countries like Australia and the USA, state-level policies can diverge significantly, reflecting a wide range of market conditions and regulatory philosophies.

The right to inject excess electricity has required structural changes to many regulatory frameworks around the world as it intersects with licensing, generation and electricity sales on the one hand and balancing requirements on the other. In high penetration or under-dimensioned grids, automatic rights to inject can also have serious consequences in terms of grid stability management when consumption is low and injections are high (Australia, Austria, USA, Chile, Cyprus...). Accordingly, some countries enforce caps on injection volume, capacity or time, or require dynamic curtailment controlled by distribution operators (Australia, Germany, Japan, Spain, USA (Hawaii)). Advanced prosumer schemes are beginning to include distribution system operator-led curtailment mechanisms that ensure grid stability while maintaining prosumer participation. Net-billing schemes can be classified as prosumer-driven when the remuneration for excess generation falls below markets rates or is set by electricity market operators (generally the prosumer's electricity supplier/utility).

Third party ownership of PV systems in self-consumption environments can be a lever or barrier. For instance, PV-as-a-service with the service provider investing and leasing the PV system to the end-user already contributed to between 40% and 50% of the residential market in the USA in 2024, and there is increasing penetration of leasing models in Austria, Germany, UK, Spain. Conversely, in some countries third party ownership of self-consumption systems is not common and complex business models are required by companies that wish to propose this type of service (France). These business models could deeply transform the PV sector in the coming years, with their ability to include PV in long term contracts, reducing the uncertainty for the contractor.

PROSUMERS

Prosumers - residential consumers who generate part or all of their electricity - occupy a central role in the development of self-consumption. While technically any co-located generator supplies its host load, the term "prosumer" applies where both the electrical and financial flows occur within the same meter boundary. The rise in number of PV prosumers has been enabled by the falling cost of PV and the increasing alignment between PV generation costs and retail electricity prices. However, the deployment of prosumer PV has also required structural adjustments to regulatory frameworks, particularly to grant the right to inject surplus electricity into the grid. That said, regulatory transitions can lead to market volatility. A sudden drop in electricity retail prices - such as in Spain during 2023 and 2024 - can diminish the attractiveness of self-consumption schemes, even in mature prosumer markets.

In regions with high PV saturation, the value of injected electricity may fall, sometimes even resulting in negative prices. In such contexts, policy may actively discourage grid exports. To maintain the economic value of their systems, prosumers are increasingly adopting batteries to maximize on-site use and reduce reliance on grid sales.

CONSUMER DRIVEN PV: PROSUMER AND ENERGY COMMUNITY / CONTINUED

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COLLECTIVE SELF-CONSUMPTION, ENERGY COMMUNITIES AND COMMUNITY SOLAR

Collective self-consumption, also called delocalised or virtual self-consumption, energy communities or community solar, is when the electricity from one or more generators is allocated to one or more consumers, either reducing or offsetting energy consumed from other suppliers through the grid. The energy flows can be physical (for example when a PV system injects to internal grids in multiple-tenancy buildings) or virtual (when generation is allocated via virtual metering and billing, using a predefined split key). The price of the electricity can be based on a negotiated per kWh fee or accessed after a share in the capital investment.

Collective self-consumption developed with the aim of widening the perimeter of self-consumption. This allows one or several PV producers (even utility-scale plants) to feed one or more consumers at a reasonable distance so that the use of the public grid is minimized. The perimeter, often initially limited to a building, has expanded in different countries to a geographical distance (10 km, 20 km radius...or across a district, region or the whole country) or set on a transformer or substation level. In this sense, some schemes compensate for real energy flows, while others are compensating for financial flows. While details may vary, the basics are similar. This widening of the perimeter to the district or regional level to include several consumers and generators has advantages for participants that include increased self-consumption ratios and more equitable access to roofs and land for self-consumption purposes (France, USA, Brazil, Lithuania, Mexico).

If well implemented, these types of systems can allow the development of new business models for prosumers, create jobs and local added value while reducing the price of electricity for consumers and energy communities. These models of production could also reduce the impacts on the grid of PV systems by encouraging consumers to adapt their consumption to solar generation hours.

The economic viability of collective self-consumption projects is built not only on retail and wholesale electricity prices and generation prices but also on the contributions participants must pay to grid access and the level of taxes on consumption and generation. There has been strong interest in particular in Austria, Italy, France, Spain, the USA and to a lesser extent Portugal, Canada, Norway Sweden, Switzerland, Germany.

In Italy, there are incentives for systems up to 1 MW in groups behind the same substation. In Sweden, it had been allowed through microgrids since 2021. In Germany, building owners can produce and sell electricity to their tenants which makes the investment more attractive. In Spain public policies and subsidies promote energy communities, with new programmes launched in 2024 to subsidise projects that integrate heat, storage, mobility and demand management. Within the USA, the Inflation Reduction Act included significant tax credit bonuses for collective self-consumption projects that met certain size, location, and equitable distribution of benefits requirements; nearly half of the states have passed legislation enabling virtual collective self-consumption (referred to within the USA as "community solar"), with many including requirements for participation of low-income households. Other countries have some definitions, but these are not yet fully implemented. In Austria, electricity traded in energy communities benefits from tax exemptions and reduced grid tariffs. In Switzerland collective self-consumption is allowed by most DSOs, but consumers have to be contiguous and not use the public grid. In Norway consumers on the same property can share and self-consume electricity produced from a PV system of up to 1 MW. In the USA and Australia community and edge-of-grid rural microgrids are emerging to reduce the cost of electricity consumption and provide local resilience through storage and backup power (sometimes in response to infrastructure destroyed in fires). In France, virtual self-consumption operations can cover a perimeter of up to 20 km and there are simplified administrative and legal procedures for social housing operators running operations on multi-tenancy buildings; generators can access the FIT for excess electricity not immediately self-consumed. Generators in France are increasingly looking to energy community frameworks as a simplified access to local electricity consumers, bypassing electricity markets. Network pricing regulations differ, and, in some countries, exemptions are used to encourage projects whilst in others full network charges must be paid even for locally transmitted electricity, which acts as a barrier to collective self-consumption or virtual net-metering.

As the number of energy communities increase year on year in countries, business models, tools and competent professionals become more accessible, further accelerating deployment.

CONSUMER DRIVEN PV: PROSUMER AND ENERGY COMMUNITY / CONTINUED

IN THE EU CONTEXT

The EU "Clean Energy Package" introduced new provisions on energy market design and frameworks for new energy initiatives. The renewable energy directive (REDII) and the electricity market directive (EMDII) provide basic definitions and requirements for the activities of individual and collective self-consumption. The European Union introduced the concept of Renewable Energy Communities (REC) and Citizen Energy Communities (CEC). REC should allow citizens to sell renewable energy production to their neighbours, while some crucial components are the definition of the perimeter and the tariffication for grid use. Those key components are defined in the national implementation in member states. This concept of energy communities is expanding not only the existing PV market segments and allowing electricity cost reductions for consumers not able to invest in solar installation themselves, but pushing a closer integration of consumers with their local communities and electricity markets as tools, supported by European research, development and innovation funding, are developed to facilitate seamless optimisation of energy communities. In Europe, the Federation of energy communities RESCoop continues to grow, with over 2500 member organisations representing more than 2 million citizens (+0.5 million compared to 2023).

IN THE USA

The term Energy Community has a different meaning in the USA, modified by the Inflation Reduction Act. It refers to communities that have been historically adversely impacted or are at risk of being adversely impacted in the future by the energy transition. The use of the term Community Solar in the USA is closer to the definition of collective self-consumption than the EU REC. Solar communities are growing under the impetus of IRA subsidies and state-led legislation – with often sharp crossovers joining community solar to energy communities; for example, Maryland, Minnesota and New Jersey have similar programmes that require community solar facilities to deliver a minimum percentage of their output to low- and moderate- income subscribers. By the end of June 2024, community solar had an estimated capacity of 7.87 GW AC, with 75% of this power in just four states (Florida, New York, Massachusetts and Minnesota).

ENERGY TRANSITION LEVER POLICIES

SUSTAINABLE BUILDING REQUIREMENTS

The building sector has a major role to play in PV development and sustainable building regulations drive PV's deployment in countries where the competitiveness of PV is close. These regulations include requirements for new building developments (residential and commercial) but also, in some cases, on properties for sale. PV may be included in a suite of options for reducing the energy footprint of the building or specifically mandated as an inclusion in the building development.

The publication of the European Commission's Solar Strategy in 2022 is part of the REPowerEU package. It presents four initiatives to overcome the remaining short-term challenges and the first of them is promoting quick and massive PV deployment via the European Solar Rooftops Initiative. Member states are incorporating this initiative in different ways into their national regulations.

In Austria, the federal support schemes have a 30% bonus for building integrated PV whilst many counties have regulations or incentives for building a PV system, with mandatory solar in Vienna and Styria for commercial and apartment buildings, with specific details in both cities. France has mandatory solar or living roofs for commercial and industrial buildings or covered car parks. For 2024, the draft Energy-Climate Strategy proposed a goal of 55% of future PV on residential/commercial rooftop systems and 10% on large-scale industrial rooftop systems. In Germany, in Berlin, solar became mandatory on many new buildings in 2023 whilst in the Netherlands, buildings must aim to be nearly energy neutral since 2021, pushing solar. In Switzerland, in 2024, a one-time payment about 10% higher than for building-applied PV (BAPV) systems under 100 kW is available. Alongside federal subsidies, some local authorities provide extra incentives, such as a 50% bonus for PV facades. Innovative BIPV projects - for heritage buildings or energy self-sufficient structures, for example, have been funded through a special government program. Some cantons have since extended these measures, offering bonuses for heritage buildings. BIPV is also promoted through permitting rules for culturally significant structures. In Denmark, the national building code has integrated PV to reduce the energy footprint, and since 2024, the energy authorities have sketched a support program for photovoltaics on residential buildings with more than 2 floors. In Italy, capital subsidies have been introduced to promote PV on public buildings in some regions. In Tokyo, Japan, solar is mandatory on most new residential buildings from 2025. The government set the targets to ensure all new buildings are net zero energy by 2030, and that 60% of new detached dwellings have solar. In the UK, discussion over 2024 is likely to lead to mandatory solar on new residential buildings from 2027. In Korea, the NRE Mandatory Use for Public Buildings Programme imposes on new public institution buildings with floor areas exceeding 1000 square meters to source more than 10% of their energy consumption from new and renewable sources. In the USA, California has had mandatory solar for certain new residential buildings since 2020 and extended this to non-residential and high-rise multifamily buildings in 2023 whilst also requiring a solar plus storage system, rather than just a solar system. In India, some states have mandatory solar supply policies for new buildings.

Beyond overall building performance regulations, rising questions around the public acceptability of utility-scale PV is pushing a number of governments to actively encourage or mandate solar in very particular segments – from Japan's program supporting research, guidelines and demonstrators for wall-integrated PV (including semi-transparent and perovskite cells) to France's mandatory solar on impermeable car parks. The goal of occupying low-conflict surfaces is pushing solar too.

ELECTRIC MOBILITY

Electric mobility is a key tool in the "electrification of usages", part of many energy transition strategies. On one hand, mobile batteries can be a useful complement to stationary batteries, and on the other, the increased electricity consumption can push consumers to PV to manage running costs.

The electrification of transport continued its strong global growth in 2024, with 17 million Electric Vehicles (EVs) sold during 2024 (+25% on 2023), representing 22% of all car sales worldwide. China led this growth with 11 million EV sales, or about two-thirds of the global market. EV's represented almost half of new car sales in China, while Europe and the USA remained at 20% and 10% respectively.

In Europe, EU directives aim for 100% zero-emission vehicles sales by 2035 (2030 in the Netherlands, Denmark). The UK, Canada and USA (California) have implemented progressively increasing Zero- Emission Vehicle (ZEV) targets tending to 100% ZEV in 2035. Norway is on track to achieve its goal of 100% ZEV sales by 2025, having reached 88% already in 2024.

EV market share rose in 14 of the 27 EU countries, although major markets like Germany and France stagnated due to reduced or phased out subsidies. New or extended EV incentives were in place in several countries (Spain, France, Greece, Ireland, Portugal). Switzerland provided no federal subsidies but maintained support through cantonal schemes. Japan continued offering subsidies under its Clean Energy Vehicle programme; however, EV adoption remains relatively low. In India, the PM E-Drive incentive programme targeted only electric two- and three-wheelers and buses, excluding private cars. Korea revised

ENERGY TRANSITION LEVER POLICIES / CONTINUED

its EV subsidies program, tightening eligibility based on battery type, price and vehicle range, measures that largely favour local manufacturers. China notably increased EV demand through enhanced trade-in incentives, while the USA continued, at least for 2024 EV credits under the Inflation Reduction Act, despite stricter sourcing requirements.

Several countries recently phased out direct subsidies (Belgium, Germany, the Netherlands, Austria), largely due to budget constraints. Countries with high penetration rates or good uptake, such as Norway, Sweden supported the roll out of electric vehicles for many years but have stopped incentives or shifted to indirect support (Denmark).

The EU's Alternative Fuels Infrastructure Regulation (AFIR), in effect since April 2024, mandates EV charging infrastructure along the TEN-T network every 60 km by 2025. Germany's Deutschlandnetz initiative is rolling out 1 000 fast-charging hubs nationwide by 2026. China continued its infrastructure expansion, adding approximately 850 000 new charging points in 2024 alone

HYDROGEN PRODUCTION.

Solar fuels, storage and other hydrogen-based applications will require massive PV, wind and other RES development if hydrogen is to be "green". Distributed Hydrogen production could be driven by distributed PV as well, pushing for higher demand for distributed PV-H2 production.

Nineteen (19) countries published hydrogen strategies in 2024, bringing the total to 60 countries with the most recent additions coming from Africa, ASEAN and Europe. At the same time, several governments revised their hydrogen targets - Portugal increased its target to 2 GW, Japan raised its hydrogen consumption target to 3 Mt/year by 2030 and 12 Mt/year by 2040, and Australia introduced a new national hydrogen strategy backed by a USD 14.8 billion industrial plan.

In Europe, the EU innovation Fund has allocated over 2 billion to more than 25 green hydrogen projects. In Germany, approximately 150 MW of electrolysers are built with announcements for 13.4 GW up to 2030, in Sweden a 740 MW electrolyser will power a steel plant. In the MENA region, large-scale hydrogen export projects linked to solar and wind advanced in Saudi Arabia and Morocco. In India, tenders were launched for 1.5 GW of electrolyser capacity in 2024 (but were later cancelled in mid-2025). Increasingly large projects are in study or capitalisation phases, including the 70 GW renewables/3.5 million ton of H2 Western Green energy Hub in Australia, the 30 GW/1.7 million ton Aman Green Hydrogen Project in Mauritania and the 26 GW/11.6 million ton Australian Renewable Energy Hub project. Capacity continues to grow in China, with an estimated of 50% of global capacity by the end of 2024.

Green hydrogen production gained significant momentum in 2024, as regional and national programmes continued to promote hydrogen deployment. However, public funding for the supply side is almost 50% higher than the demand side, raising concerns that many projects could struggle to secure long-term offtake without stronger market signals.

ELECTRICITY STORAGE

The cost of storage is pursuing its steep decline after a short halt in 2022 - and storage is becoming more attractive in a growing number of markets. Due to the cost decline of storage, solar power plants with onsite storage are increasingly attractive for developers and residential customers as the combination with storage allows them to smooth the power output, to deliver ancillary services or to reduce connection costs if peak injection is reduced reduce space between paragrpahe to align with all others.

In China, the storage market grew significantly, with 37 GW new storage stations commissioned, more than doubling the new capacity installed in 2023. This growth was driven by national targets and regional mandates for storage in PV projects. Australia also experienced notable growth, with 7.8 GW of utility storage being constructed in 2024, supported by federal and state-level incentives. In Europe, Austria, Spain and Germany continued or expanded their support schemes for battery storage, through auctions and national funding programmes. In Belgium, the largest battery storage project in Europe has been scaled up to 700 MW) with construction expected to start in the summer of 2025. In the USA, federal tax credits under the Inflation Reduction Act and state-level procurement mechanisms continued to drive battery deployment, with major hybrid solar-plus-storage projects coming online, including the commissioning of the Edwards-Sanborn facility, the largest operational battery system worldwide. In Japan, the first capacity auction resulted in over 1 GW of storage capacity being allocated. India launched tenders for battery storage projects linked to renewable energy, and in Chile, another emerging market, a hybrid project combining PV with one of the world's largest battery systems has been approved. South Africa continued implementing policies to promote battery storage through national programmes aiming to improve grid resilience and reliability. In the MENA region, governments have increasingly included battery storage in their national energy strategies and procurement plans, with large-scale tenders under development or underway in countries such as Saudi Arabia and the United Arab Emirates to support ambitious renewable deployment targets.

Storage is a key element of a carbon neutral energy system relying on RES electricity; the European Commission actively supports energy storage through research and innovation funds. Some consider that storage development for PV electricity will be massively supported through electric vehicles connected to the grid during a large part of the day, able to store and deliver energy to consumers at a larger scale than simple batteries. These vehicle-to-grid or V2G concepts are being explored and tested in several countries, with the Netherlands, Switzerland and Japan as front-runners, with at least one V2G project selling on the electricity market.

INDUSTRIAL AND MANUFACTURING POLICIES

Industrial and manufacturing support schemes for PV have historically required long lead times. While favourable policy discussions emerged globally from 2021, major support measures began materialising in 2022 and 2023. These include the USA Inflation Reduction Act (IRA – modified, but not repealed by 2025's One Big Beautiful Bill Act)) and a suite of EU-level strategies such as the Green Deal Industrial Plan, the Net-Zero Industry Act (NZIA), and the Critical Raw Materials Act, which became operational in 2024. Collectively, they created frameworks for tax credits, CAPEX support, permitting simplification, and local content incentives. The European Solar PV Industry Alliance, launched in late 2022, scaled up its coordination role in 2024, while national support programmes in Spain, Italy, and the Netherlands (reduced in 2025) entered implementation whilst indirect support for local manufacturing, such as bonuses in support mechanisms for using local modules, were in place in Austria and Italy (Transizione 5.0).

Australia introduced the AUD 1 billion Solar Sunshot programme in 2024, supporting full upstream manufacturing, as part of its broader Future Made in Australia strategy. In India, execution of the Production Linked Incentive scheme accelerated in 2024, with allocation rounds underway for large-scale capacity expansion. In Türkiye, YEKA tenders continue to prioritise domestic content.

Meanwhile, China's overcapacity build-up, primarily through private investment, led to record-low module prices in 2023-2024, placing pressure on manufacturers globally. In response, policy incentives are increasingly coupled with supply chain resilience goals and strategic trade instruments. For instance, discussions in 2024 on extending the Carbon Border Adjustment Mechanism (CBAM) to PV components aim to reinforce EU manufacturing competitiveness. Despite these efforts, successful implementation remains contingent on understanding the full complexity of PV value chains and ensuring access to globally constrained inputs such as high-purity quartz, glass, and silver. Not all announced initiatives are likely to reach commissioning, but the overall industrial momentum in 2024 represents a decisive shift from planning to execution.

four

TRENDS IN PV INDUSTRY

This chapter provides a brief overview of the upstream and downstream sectors of the PV industry intending to provide highlights during 2024 and the first half of 2025. The first part provides manufacturing activities of the upstream sector of the PV industry from feedstocks (metallurgical grade silicon, (MG-Si), polysilicon, ingots, blocks/bricks and wafers) to PV cells and modules described in Figure 4.1. The second part provides activities of the balance-of-system (BOS) sector that include components (inverters, mounting structures, charge regulators, storage batteries, appliances, etc.), and project development and operation and maintenance (O&M).

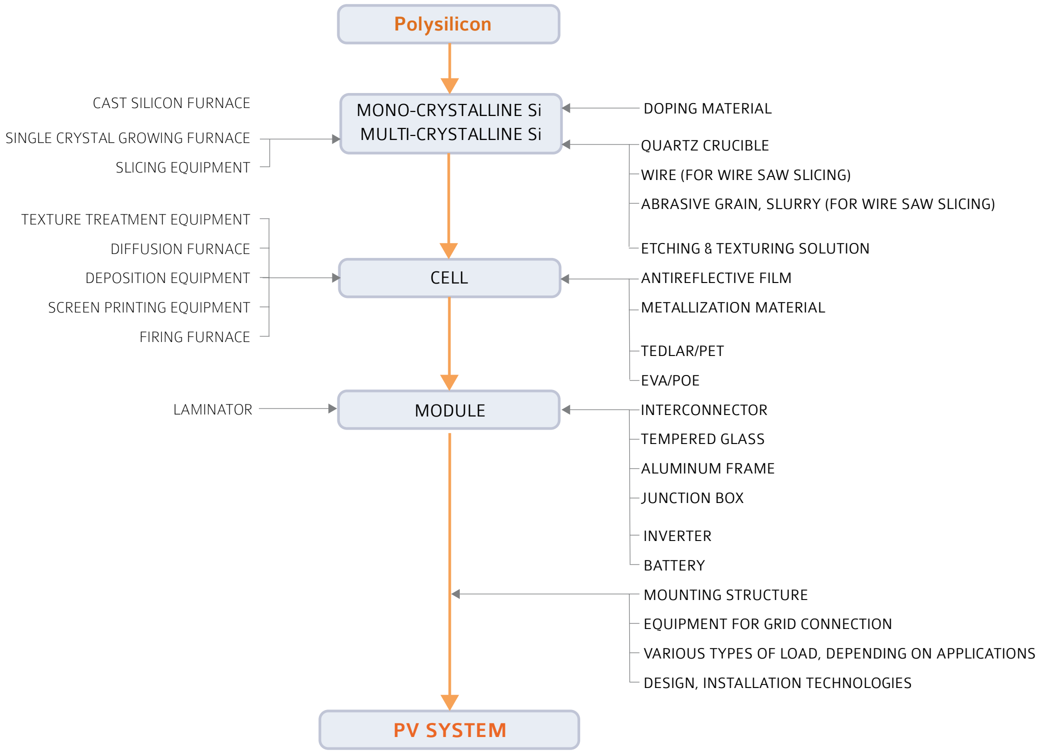
In 2024, global production of photovoltaic (PV) modules reached 726 GW, representing an 18.5% increase from 2023. This marks a significant slowdown compared to the 61.7% year-on-year growth observed between 2022 and 2023. Among the total production, 94.5% originated in IEA PVPS member countries, with China maintaining its dominant role. The country accounted for 86.4% of global PV module production. Manufacturing capacity worldwide expanded further, reaching 1 405 GW/year, of which 83% was located in China. This underscores China's continued leadership in both PV module production and consumption. Beyond module manufacturing, China also retains a leading position in the inverter market, with estimates indicating that over 80% of global inverter shipments originate from Chinese companies.

As illustrated in Figure 4.2, manufacturing capacity continued to exceed demand, and module spot prices fell below 10 US cents/W from the end of May 2024. This trend was primarily driven by overcapacity throughout the PV supply chain (Figure 4.3). Prices fell below production costs, contributing to intensified competition and industry strain - a situation often described as "involution." In response, the Chinese government introduced revised criteria for capacity expansion and market entry in the PV manufacturing sector, aiming to curb uncontrolled growth. Consequently, the pace of new capacity additions in China has begun to slow.

Despite China's dominance, developments in 2024 showed continued progress in diversifying manufacturing bases. In the USA, module production capacity is sufficient to meet domestic demand. But production has not yet fully ramped, and this is also only true for modules, not cells or wafers. India also advanced its manufacturing capacity, supported by the Production Linked Incentive (PLI) scheme, and is emerging as a potential exporter of PV modules. In the European Union, the Net Zero Industry Act (NZIA), adopted in 2024, alongside national support mechanisms, is expected to contribute to increased capacity. However, expansion in Europe remains slower than in the USA and India. Protective trade measures, such as multiple import tariffs in the USA, and India's Basic customs duty (BCD), appear to support domestic industry development. Tariff structures and incentive frameworks are expected to further promote the diversification of global manufacturing locations.

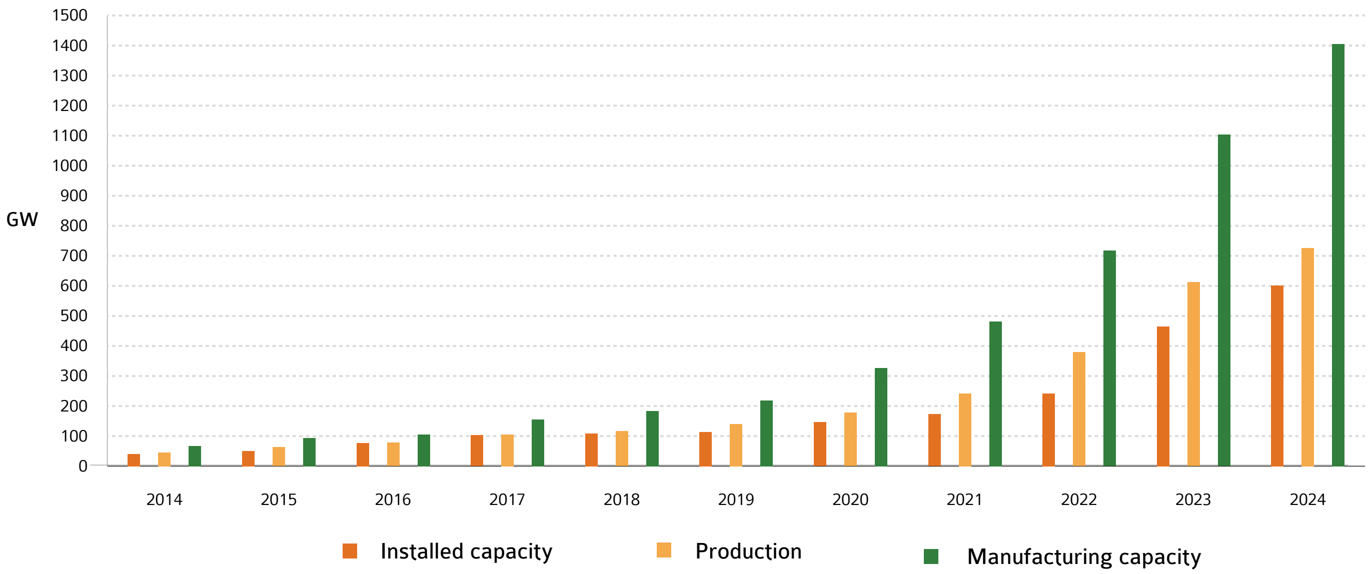
In terms of cell technology, crystalline silicon remains the mainstream. However, a notable transition is underway: PERC cell production is in decline while TOPCon technology has become the dominant cell architecture.

FIGURE 4.1: PV SYSTEM VALUE CHAIN



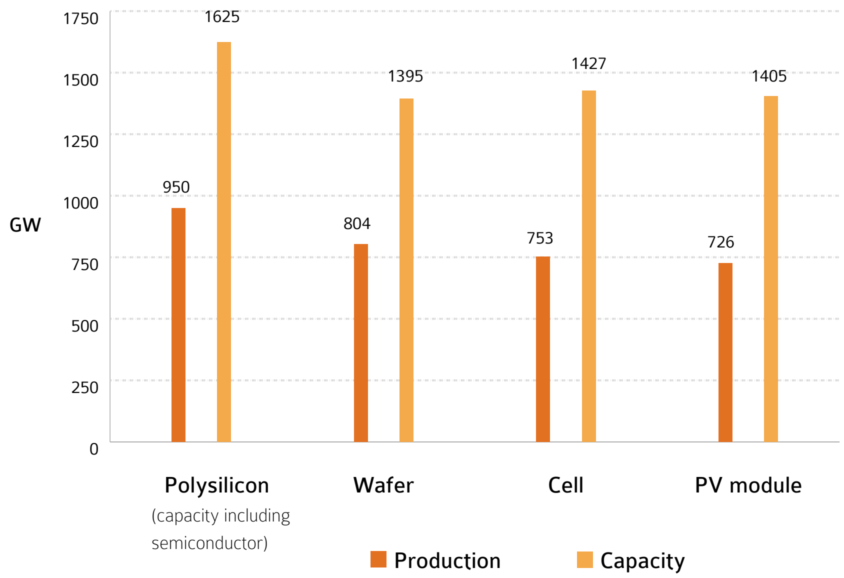
SOURCE: IEA PVPS & OTHERS

FIGURE 4.2: YEARLY PV INSTALLATION, PV PRODUCTION AND PRODUCTION CAPACITY 2014-2024 (GW)



SOURCE : EA PVPS, RTS CORPORATION

FIGURE 4.3: PRODUCTION AND PRODUCTION CAPACITY ALONG THE PV VALUE CHAIN IN 2024



SOURCE: IEA PVPS, RTS CORPORATION

THE UPSTREAM PV SECTOR

SILICON METAL PRODUCTION

Crystalline silicon solar cells are manufactured using polysilicon, which in turn is derived from Metallurgical Grade Silicon (MG-Si). In 2024, global MG-Si production capacity reached 8.8 million tons per year, representing a 3.1% increase compared to 2023. China accounted for the majority of this capacity, with 7.28 million tons per year, or approximately 83% of the global total.

China also remained the largest producer, with an output of 4.7 million tons in 2024 - equivalent to around 70% of global MG-Si production. Historically, MG-Si manufacturing in China has been concentrated in the Xinjiang Uygur Autonomous Region. However, recent developments indicate a trend toward geographic diversification. For example, the Tongwei Group commenced operations at two new MG-Si facilities in Inner Mongolia, with a combined annual capacity of 300 000 tons.

POLYSILICON PRODUCTION

In 2024, global polysilicon production - including volumes for both photovoltaic and semiconductor use - reached approximately 1.96 million tons, representing a 21.7% increase from the previous year. Although production continued to grow, the rate of growth slowed considerably compared to the 61% increase recorded in 2023. Of the total volume, it is estimated that around 1.9 million tons were produced specifically for PV applications.

By the end of 2024, global polysilicon manufacturing capacity had expanded to 3.25 million tons per year. Figure 4.4 illustrates the recent evolution of global polysilicon production.

China maintained its dominant position in global polysilicon production in 2024, accounting for approximately 1.82 million tons of output. Among the IEA PVPS member countries outside of China, production was also recorded in Germany, the USA, Malaysia, Korea, and Japan. However, polysilicon production in Korea and Japan is limited to semiconductor applications. Figure 4.5 presents the distribution of global polysilicon production by country.

Despite the existing imbalance between supply and demand, global polysilicon manufacturing capacity is expected to continue expanding. If currently announced projects proceed as planned, capacity could grow from 3.25 million tons per year in 2024 to 5.00 million tons per year by 2025. New production initiatives have also been reported in India, Oman, the USA, and Australia, supported by industrial policy measures aimed at strengthening domestic PV supply chains. Nevertheless, ongoing price pressure

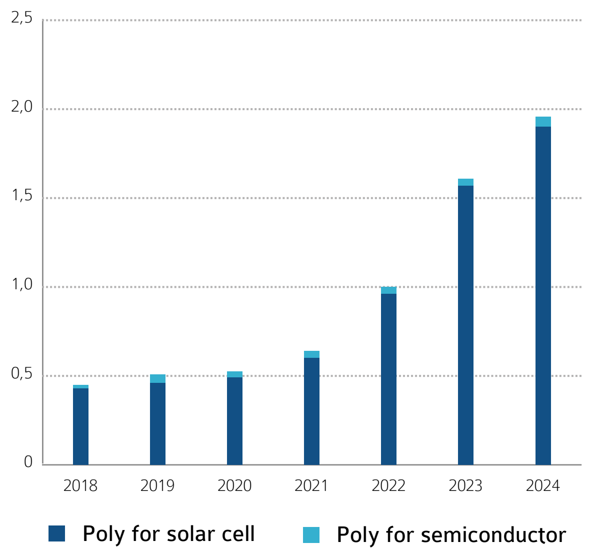
THE UPSTREAM PV SECTOR / CONTINUED

in the polysilicon market may pose a risk to future investment decisions and delay the construction of new production facilities. The spot price of polysilicon remained under pressure throughout 2024 due to persistent overcapacity in the market. By the end of December 2023, the spot price had declined to USD 7.28/kg, and continued its downward trajectory to reach USD 4.42/kg by the end of December 2024. In response to these sustained low price levels, two of China's largest polysilicon manufacturers - Tongwei Group and Daqo - announced production cuts on December 24, 2024, in an effort to stabilize the market.

Shortly thereafter, on December 26, 2024, China officially launched a futures trading market for polysilicon. The contract size is set at 3 tons per lot, with trades denominated in RMB. A daily price fluctuation limit of ±14% relative to the previous day's closing price was established. The introduction of this market is expected to provide producers with a new mechanism to hedge against the risk of price volatility.

In terms of production methods, the majority of polysilicon used in solar cells continues to be produced via the Siemens process. However, granular polysilicon manufactured using the fluidized-bed reactor (FBR) process - known for its lower production cost - is also gaining market share. GCL Technology in China has an FBR-based production capacity of 480 000 tons per year. In 2024, granular polysilicon accounted for approximately 14% of total polysilicon output in China.

FIGURE 4.4: GLOBAL POLYSILICON PRODUCTION (IN MILLION TONS)



Source: IEA PVPS, RTS Corporation

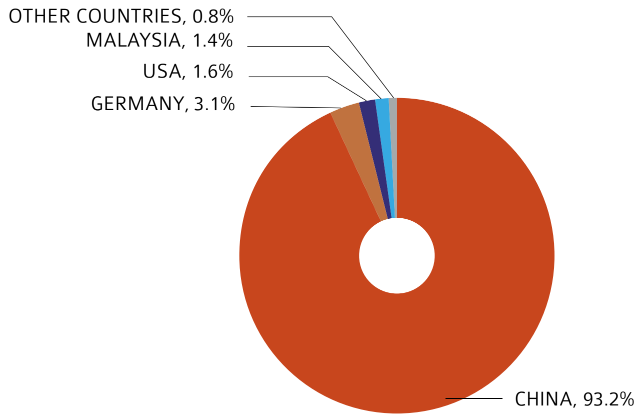
Amid ongoing price pressure, the decline in polysilicon consumption intensity has continued steadily. In 2015, the amount of polysilicon required per watt for solar cell production stood at 5.6 grams. By 2024, this figure had dropped to approximately 2 grams per watt.

This reduction has been driven by several technological advancements, including the widespread adoption of thinner wafers, the transition to higher-efficiency N-type monocrystalline silicon, and the implementation of advanced cell architectures such as TOPCon and heterojunction (HJT) technologies. Additionally, improvements in wafer slicing techniques have reduced kerf loss, further lowering material consumption.

Looking ahead, some manufacturers of N-type solar cells are planning to reduce wafer thickness even further. As a result, the downward trend in polysilicon consumption per watt is expected to continue.

INGOTS & WAFER

FIGURE 4.5: SHARE OF PV POLYSILICON* PRODUCTION IN 2024 BY COUNTRY



* including polysilicon for semiconductors

SOURCE: IEA PVPS, RTS Corporation

THE UPSTREAM PV SECTOR / CONTINUED

Global wafer production reached 804 GW in 2024, representing an 18% increase compared to the previous year. As shown in Figure 4.7, China maintained its dominant position in this segment of the PV value chain, accounting for 776 GW - or approximately 97% - of global wafer output.

In addition to China, wafers were also produced in countries such as Vietnam, Thailand, and Malaysia. These locations have attracted investments from major Chinese manufacturers seeking to establish overseas production bases in order to circumvent tariffs on Chinese products entering the USA. Nonetheless, production volumes in these countries remain relatively limited in scale.

Global wafer manufacturing capacity expanded significantly in 2024, reaching 1 395 GW/year - an increase of 43% from the previous year. Of this total, China accounted for 1 349 GW/year, further reinforcing its leading role in wafer production capacity worldwide.

While China currently dominates global wafer output, production is expected to diversify further in the coming years as more countries seek to strengthen their positions in the PV supply chain.

In India, wafer manufacturing is gaining momentum, supported by targeted policy measures to develop a domestic PV industry. Several factories have begun operations, and future expansion is planned. According to the National Solar Energy Federation of India (NSEFI), crystalline silicon wafer manufacturing capacity is projected to grow from 6 GW/year in 2025 to 100 GW/year by 2030. Key Indian companies - including Waaree Energies, the Adani Group, Premier Energies, and Reliance Industries - are developing vertically integrated production lines, encompassing the full value chain from wafers to PV modules.

In the USA, new crystalline silicon ingot and wafer manufacturing facilities are also expected to commence operations by the end of 2025. For instance, Qcells, a subsidiary of Hanwha Solutions (Korea), is establishing a vertically integrated plant in Cartersville, Georgia. The facility will have a production capacity of 3.3 GW/year and will cover ingot, wafer, solar cell, and module manufacturing. Additionally, Corning Inc. has announced plans to enter the wafer manufacturing segment. The company intends to produce crystalline silicon wafers adjacent to its subsidiary Hemlock Semiconductor's polysilicon plant in Michigan.

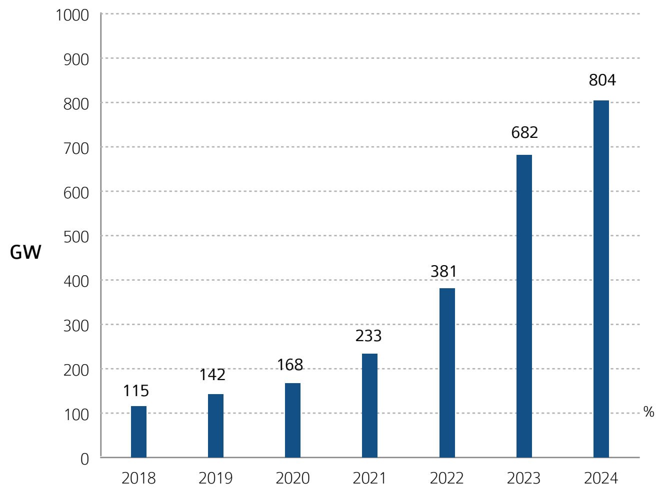
Beyond India and the USA, emerging plans for wafer production have also been reported in Indonesia and Laos.

In 2024, nearly all crystalline silicon wafers used in solar cell manufacturing were of the single crystalline (sc-Si) type. Within this category, n-type wafers experienced a rapid rise in adoption, increasing their market share from 30% in 2023 to 70% in 2024, and thereby becoming the dominant technology.

Wafers are also evolving in terms of size and shape. The M10 standard (182 mm square) and larger formats became the mainstream, while the M6 standard (166 mm square) is expected to be phased out after 2025. Rectangular wafers, in particular, are anticipated to gain substantial market share, with even larger sizes such as the G12 standard (210 mm square) expected to enter the market in the near future.

Price trends for wafers reflected the ongoing imbalance between supply and demand. In January 2024, n-type sc-Si wafers of size

FIGURE 4.6: GLOBAL WAFER PRODUCTION (IN GW)



SOURCE: IEA PVPS, RTS Corporation

182.2 mm × 183.75 mm (G10L standard, 130 µm thickness) were priced at 14.2 USD/piece. Prices spiked temporarily, reaching 19.0 USD/piece by the end of April. However, as oversupply persisted and inventory levels remained high despite production cutbacks, prices fell sharply. By the end of May 2024, the same wafers were trading at 12.0 USD/piece. At the end of December 2024, prices had stabilized slightly at 12.8 USD/piece - marking a historic low that resulted in financial losses for all wafer manufacturers.

The main driver behind this price decline was the widening supply-demand gap. However, ongoing cost reductions - enabled by thinner wafers and reduced kerf loss through advancements in slicing technologies - also contributed to the downward pressure on prices.

THE UPSTREAM PV SECTOR / CONTINUED

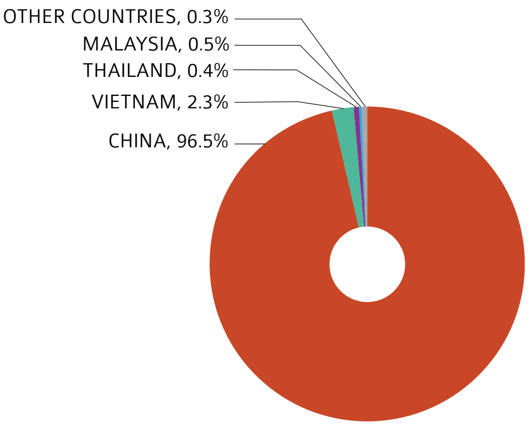
SOLAR CELL PRODUCTION

Global production of solar cells - including thin-film technologies - reached 753 GW in 2024. This represents a year-on-year growth rate of 17%, a marked slowdown compared to the 63% increase observed in 2023. Figure 4.8 illustrates the global trend in solar cell production over recent years.

PRODUCTION AND PRODUCTION CAPACITY

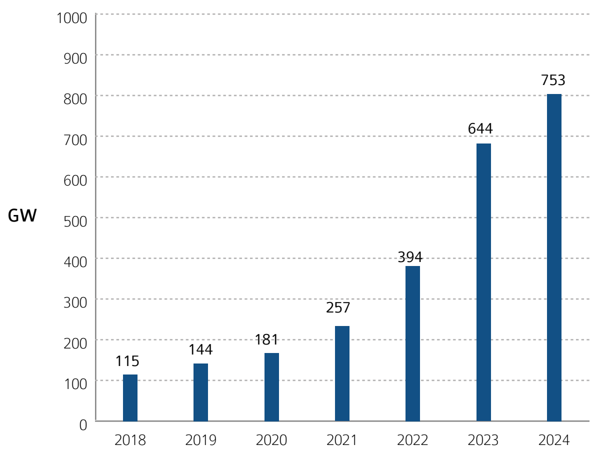
Global production of solar modules - including both crystalline silicon and thin-film technologies - reached 726 GW in 2024, representing a 19% increase compared to the previous year. This marks a significant slowdown from the 62% growth recorded between 2022 and 2023, indicating a deceleration in the pace of production expansion. Figure 4.10 illustrates the recent trends in global PV module production volumes.

FIGURE 4.7: SHARE OF PV WAFER PRODUCTION - 2024 BY COUNTRY



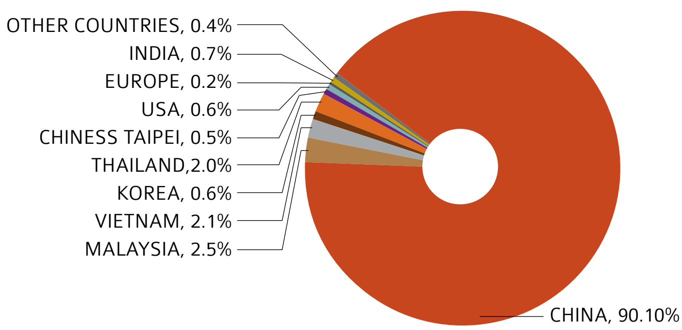
SOURCE: IEA PVPS, RTS CORPORATION

FIGURE 4.8: GLOBAL PRODUCTION AMOUNT OF SOLAR CELL INCLUDING THIN-FILM (IN GW)



SOURCE: IEA PVPS, RTS CORPORATION

FIGURE 4.9: SHARE OF PV CELL PRODUCTION - 2024 BY COUNTRY



SOURCE IEA PVPS, RTS CORPORATION

As of the end of 2024, global solar cell manufacturing capacity reached 1 427 GW/year. China continued to dominate, holding approximately 1 302 GW/year, or 91% of the global total. However, the geographic distribution of cell production is expected to diversify in the near future, particularly with expansions underway in the USA and India.

According to an analysis by Clean Energy Associates (CEA), USA. crystalline silicon solar cell manufacturing capacity is projected to reach 13 GW/year by the end of 2025. In India, cell production capacity was reported to have reached 15 GW/year by May 2025, and the National Solar Energy Federation of India (NSEFI) forecasts this figure will grow to 120 GW/year by 2030. Additional plans for cell manufacturing have also been announced in Indonesia and several Middle Eastern countries, indicating growing regional interest in PV value chain localisation.

A major shift in solar cell technology occurred in 2024. While p-type PERC cells held the largest market share in 2023 at approximately 64%, their share dropped sharply to around 20% in 2024. The mainstream position was overtaken by TOPCon-type crystalline silicon cells, whose market share rose from about 30% in 2023 to 70% in 2024. Other technologies, such as heterojunction (HJT) and back-contact (BC) cells, remained below 5% market share each.

In terms of pricing, n-type monocrystalline silicon cells were priced at USD 0.056/W in January 2024 and remained at that level during the early part of the year. However, prices declined sharply mid-year, dropping to USD 0.044/W in May and further to USD 0.034/W in June. By the end of December 2024, the spot price had reached USD 0.033/W - a historically low level for the segment.

One of the key challenges facing the solar cell industry is the reduction of silver consumption. According to the Silver Institute,

THE UPSTREAM PV SECTOR / CONTINUED

total global silver demand in 2024 was 1 164 million ounces, with approximately 17% - or 197.6 million ounces - used in solar cell manufacturing. Rising silver prices, driven by supply-demand imbalances, are adding cost pressure, particularly as the industry scales toward terawatt-level deployment.

In response, efforts are underway to reduce silver usage through several strategies. These include the adoption of low-temperature silver-coated copper pastes, copper particle-based screen printing, and structural innovations such as busbar-less designs and advanced cell-to-cell interconnection technologies. These approaches aim to lower material costs while maintaining high cell performance.

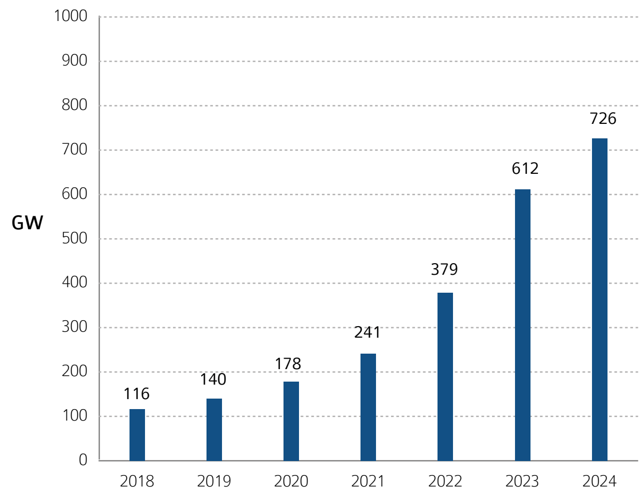
TABLE 4.1: GLOBAL TOP FIVE MANUFACTURERS (BRANDS) IN TERMS OF PV CELL/MODULE PRODUCTION AND SHIPMENT VOLUME (2024)

RANK	SOLAR CELL PRODUCTION (GW)		PV MODULE PRODUCTION (GW)		PV MODULE SHIPMENT (GW)	
1	TONGWEI SOLAR	89.1	JINKOSOLAR	89.8	JINKOSOLAR	92.9
2	JINKOSOLAR	81.3	JA SOLAR TECHNOLOGY	72.1	LONGI GREEN ENERGY TECHNOLOGY	75.8
3	JA SOLAR TECHNOLOGY	70.4	LONGI GREEN ENERGY TECHNOLOGY	70.2	JA SOLAR TECHNOLOGY	74.2
4	LONGI GREEN ENERGY TECHNOLOGY	60.8	TRINA SOLAR	66.0	TRINA SOLAR	70.5
5	TRINA SOLAR	59.4	TONGWEI SOLAR	50.0	TONGWEI GROUP	45.7

NOTE: PRODUCTION VOLUMES ARE MANUFACTURERS' OWN PRODUCTION, WHEREAS SHIPMENT VOLUMES INCLUDE COMMISSIONED PRODUCTION AND OEM PROCUREMENT.

SOURCE IEA PVPS, RTS CORPORATION

FIGURE 4.10: GLOBAL PV MODULE PRODUCTION (IN GW)



SOURCE: IEA PVPS, RTS CORPORATION

As with other segments of the PV value chain, China remained the global leader in PV module production in 2024. The country had a manufacturing capacity of 1 156 GW/year and produced 627 GW of PV modules - representing approximately 86% of global output.

Odriven by domestic policy incentives and industrial development efforts.

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Outside of China, production was more modest but still notable. India produced 24 GW of PV modules, followed by the USA with 23 GW, Vietnam with around 20 GW, Thailand with approximately 10 GW, and Malaysia with about 7 GW. Additional production also took place in countries such as Canada, Japan, Turkiye, Cambodia, Chinese Taipei, Mexico, and various European nations.

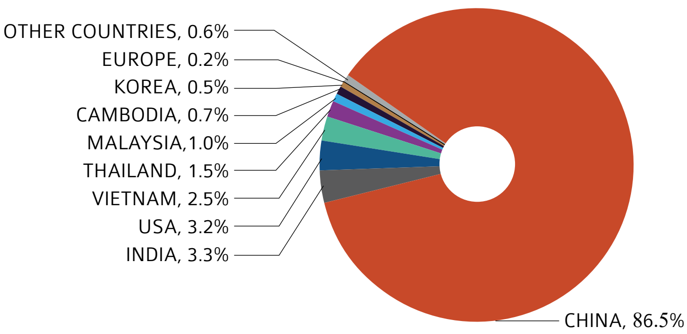
Among the countries producing PV modules, the USA and India notably expanded their manufacturing capacities in 2024. By the end of the year, module production capacity reached 42.1 GW/year in the USA and 61 GW/year in India, reflecting substantial growth driven by domestic policy incentives and industrial development efforts.

In Southeast Asia, PV module manufacturing in Vietnam, Thailand, Malaysia, and Cambodia primarily served the USA. market. However, in 2023, USA. authorities determined that PV products imported from these four countries were circumventing existing trade duties on Chinese products. As a result, anti-dumping and countervailing duties were imposed starting on June 6, 2024, as well as anti-dumping duties.. This policy shift is expected to impact the viability of Southeast Asian manufacturing aimed at the USA. market. It is assumed that some producers may reduce output or relocate production, and a decline in module production as volumes imported to USA dropped in Q4 2024, from these four countries is possible moving forward.

THE UPSTREAM PV SECTOR / CONTINUED

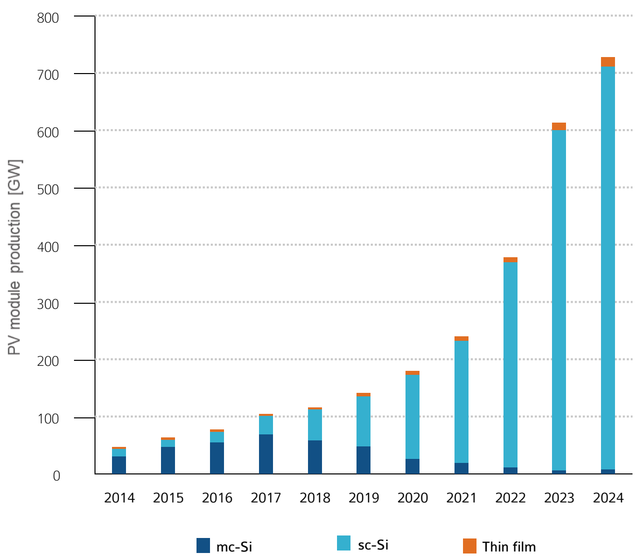
Figure 4.12 shows the distribution of PV module production by technology type. As in the previous year, crystalline silicon modules dominated the market, accounting for approximately 98% of global production in 2024. Thin-film technologies represented the remaining 2%, with the vast majority being cadmium telluride (CdTe) modules manufactured by First Solar in the USA. Other thin-film technologies - including amorphous silicon, CIGS, and organic PV - continued to be produced in smaller volumes.

FIGURE 4.11: SHARE OF PV MODULE PRODUCTION IN 2024 BY COUNTRY



SOURCE: IEA PVPS, RTS CORPORATION

FIGURE 4.12: MODULE PRODUCTION PER TECHNOLOGY IN IEA PVPS COUNTRIES 2014-2024



SOURCE IEA PVPS, RTS CORPORATION

TECHNOLOGY TRENDS

Changes have also been observed in the components and configurations of PV modules. One of the most notable trends in 2024 was the growing share of bifacial modules. According to the China Photovoltaic Industry Association (CPIA), 77.6% of crystalline silicon PV modules manufactured in China were bifacial - a significant increase reflecting both performance gains and market demand for higher energy yields.

To further reduce weight and costs, manufacturers have increasingly adopted thinner surface glass. However, this trend has raised reliability concerns. For instance, data from field incidents suggest that PV modules using 3.2 mm glass exhibit better durability under hail impact than those using thinner 2.0 mm glass, which show a higher rate of breakage.

In terms of encapsulant materials, ethylene-vinyl acetate (EVA)-based products continued to dominate, with a 54% market share in 2024. However, polyolefin (POE)-based encapsulants - offering greater durability and moisture resistance - have gained traction, particularly with the rise of n-type solar cell adoption. Due to POE's higher cost, a growing number of manufacturers have opted for EPE laminates (EVA-POE-EVA layered structures), whose market share rose from 28% in 2023 to 37% in 2024.

PV module prices remained under pressure throughout 2024, staying below USD 0.10/W. At the start of the year, the spot price of n-type single-crystalline silicon PV modules (580–625 W, using 182 mm cells) was USD 0.119/W. By the end of May, the price had declined to USD 0.099/W, and further dropped to USD 0.078/W by December 2024.

According to CPIA, the production cost (including tax and minimum cost) of a bifacial, n-type crystalline silicon module - using M10 or G12R standard wafers - was reported at RMB 0.692/W in December 2024, equivalent to approximately USD 0.0948/W at the average exchange rate for the year. As a result of these low price levels, many PV module manufacturers faced severe financial pressure, with a growing number reporting net losses in their 2024 financial results.

These challenging market conditions persisted into mid-2025. As of July 2025, several major manufacturers were reassessing their capital expenditure plans and production strategies. In response, some companies are shifting focus toward energy storage systems and integrated solutions businesses in an effort to diversify revenue streams and stabilize operations.

THE UPSTREAM PV SECTOR / CONTINUED

TABLE 4.2: EVOLUTION OF ACTUAL MODULE PRODUCTION AND PRODUCTION CAPACITIES (MW)

	ACTUAL PRODUCTION			PRODUCTION CAPACITIES			
YEAR	IEA PVPS COUNTRIES	OTHER COUNTRIES	TOTAL	IEA PVPS COUNTRIES	OTHER COUNTRIES	TOTAL	UTILIZATION RATE
1993	52		52	80		80	65%
1994	0		0	0		0	0%
1995	56		56	100		100	56%
1996	0		0	0		0	0%
1997	100		100	200		200	50%
1998	126		126	250		250	50%
1999	169		169	350		350	48%
2000	238		238	400		400	60%
2001	319		319	525		525	61%
2002	482		482	750		750	64%
2003	667		667	950		950	70%
2004	1 160		1 160	1 600		1 600	73%
2005	1 532		1 532	2 500		2 500	61%
2006	2 068		2 068	2 900		2 900	71%
2007	3 778	200	3 978	7 200	500	7 700	52%
2008	6 600	450	7 050	11 700	1 000	12 700	56%
2009	10 511	750	11 261	18 300	2 000	20 300	55%
2010	19 700	1 700	21 400	31 500	3 300	34 800	61%
2011	34 000	2 600	36 600	48 000	4 000	52 000	70%
2012	33 787	2 700	36 487	53 000	5 000	58 000	63%
2013	37 399	2 470	39 868,5	55 394	5 100	60 494	66%
2014	43 799	2 166	45 964,9	61 993	5 266	67 259	68%
2015	58 304	4 360	62 664	87 574	6 100	93 674	67%
2016	73 864	4 196	78 060	97 960	6 900	104 860	74%
2017	97 942	7 200	105 142	144 643	10 250	154 893	68%
2018	106 270	9 703	115 973	165 939	17 905	183 844	63%
2019	123 124	17 173	140 297	190 657	28 530	219 187	64%
2020	156 430	23 044	179 474	289 581	37 095	326 676	56%
2021	213 032	29 346	242 378	410 500	71 500	482 727	50%
2022	329842	48758	378600	611124	105476	716600	53%
2023	550992	61208	612200	1030500	72500	1103000	56%
2024	686140	39760	725900	1321278	84027	1405305	52%

Note: Although China joined IEA PVPS in 2010, data on China's production volume and production capacities in 2006 onwards are included in the statistics.

SOURCE: IEA PVPS, RTS CORPORATION

THE UPSTREAM PV SECTOR / CONTINUED

EMERGING TECHNOLOGIES

In several IEA PVPS member countries such as China, Japan, Korea, USA, Germany, the Netherlands and Sweden, R&D efforts on emerging PV technologies are underway. In particular, since the conversion efficiency has been rapidly improved in a short period of time, efforts toward the practical application of perovskite technology have been continued in 2024. Perovskite solar cells are expected to have the potential for high conversion efficiency, low material costs, and a low carbon footprint process.

Several companies, particularly in China, launched pilot production lines for perovskite PV modules. These modules have begun to be shipped for demonstration projects, but large-scale commercial production had not yet commenced by the end of 2024. Some companies have announced that they have passed the IEC 61215/61730 certification test. For example, UtmoLight announced in February 2024 that its commercial-sized perovskite solar cell module with an area of 0.72 m^2 had passed the IEC 61215/61730 certification test and obtained the first and only TÜV certification.

The practical application of tandem technology using perovskite solar cells and c-Si solar cells is also actively being carried out around the world. Oxford PV (UK) started small scale production of tandem cells using M6 (166 mm wafers) in their German factory. In June 2024, the company announced that it had recorded a conversion efficiency of 26.9% for a PV module with an area of approximately 1.6 m^2 (1 m x 1.7 m) (measured by FhG-ISE CalLab) Hanwha Solutions (Hanwha Q CELLS) (Korea) established a pilot production line in Talheim, (Germany) in November 2022 through a consortium with the Helmholtz Center for Materials and Energy Research Berlin (HZB) and others. In May 2023, the company announced that it would invest $100 million for the construction of a new pilot production line for tandem solar cell modules at its Jincheon plant in Korea. The plan is to start commercial production by the end of 2026.

Tongwei Group (China) plans to establish a photovoltaic industry technology research and development center in Sichuan Province, China, including a 100 MW/year perovskite/HJT tandem solar cell research and development line, and was official approved from the Sichuan Provincial Development and Reform Commission. The company announced that it had recorded a conversion efficiency of 31.68% for its perovskite/HJT tandem solar cell in November 2023. Other major Chinese companies are also working on research and development of perovskite/c-Si tandem technology, although they have not announced plans to build pilot lines. In June 2024, LONGi Green Energy Technology (China) announced that it had recorded a conversion efficiency of 34.6% for its small area perovskite/c-Si tandem solar cell (measured by EU ESTI). The company also announced that it achieved a 30.1% of conversion efficiency using M6 standard wafers (measured by FhG-ISE). Jinko Solar is also working on research and development of tandem solar cells. In May 2024, the company announced that a perovskite/c-Si tandem solar cell with an n-type TOPCon structure recorded a conversion efficiency of 33.24% (measured by SIMIT, China).

As mentioned above, research, development and demonstration of next-generation solar cells based on perovskite solar cells has been active, but neither single-junction nor tandem technologies have yet reached full-scale commercial production. It is necessary to improve conversion efficiency (to fill the gap between small-area cells and large-area modules), verify service life and stability, and establish a manufacturing process. In addition to overcoming these technical challenges, it is also necessary to identify target markets that take advantage of the characteristics of the technology, establish standardization (performance measurement and reliability evaluation), and product design as a system (construction method, etc.), as well as ensure environmental safety and respond to recycling efforts. For tandem types, durability and reliability must be verified before they can be introduced into the market of existing c-Si solar cells.

Advanced III-V technologies such as gallium arsenide (GaAs) and multijunction cells based on Ga-compounds remain specialized for space applications. However, with the ongoing cost reductions in crystalline silicon modules, their use in space applications has also expanded - particularly in response to satellite miniaturization and increased launch activity.

BALANCE OF SYSTEM

PV INVERTERS

According to Wood Mackenzie, global shipments of inverters for photovoltaic (PV) systems reached 589 GW in 2024. By early 2025, global inverter manufacturing capacity had exceeded 1 TW/year, resulting in significant overcapacity. This supply-demand imbalance, combined with the entry of new manufacturers, contributed to a decline in inverter prices across multiple market segments.

China continues to play a dominant role in inverter manufacturing, supported by its position as the world's largest PV market. Huawei and Sungrow, the top two Chinese manufacturers, accounted for over 55% of the global inverter market in 2024.

Technological developments and product diversification continued to shape the inverter market. Alongside growth in utility-scale projects, the expansion of distributed PV markets drove demand for hybrid inverters that integrate solar generation with power storage - particularly for residential and commercial applications. These systems are increasingly being used in conjunction with electric vehicles (EVs) and in virtual power plant (VPP) configurations. To support self-consumption, modern inverters now incorporate energy management functions that optimise energy flows, integrating energy storage systems and EVs with smart monitoring platforms.

Advances in artificial intelligence and machine learning have also enhanced inverter performance. These technologies are being applied to failure detection, predictive maintenance, and the optimisation of electricity generation, contributing to reduced operation and maintenance (O&M) costs.

The segment of module-level power electronics (MLPE) also saw growth in specific markets. Microinverters and DC optimizers - which operate at the individual module level - have been widely adopted in the USA. residential sector, where rapid shutdown requirements are mandated by the National Electrical Code (NEC). These technologies are now gaining traction in other markets as well, particularly in applications where safety and wiring simplification are priorities - such as public buildings in France. MLPE technologies can improve energy yields in partially shaded installations and allow for rapid and efficient shutdowns in emergency scenarios, such as during fires. In 2024, the MLPE market also expanded in Europe, driven by growing demand for plug&play or balcony PV systems.

In 2024, the market for hybrid inverters continued to grow, while string inverter capacity increased notably. Advancements in central inverter technology, particularly systems capable of handling 2 000 V, are also progressing. In addition, grid-forming (GFM) inverters - combining power conversion systems (PCS) with pseudo-inertial capabilities and storage - are being introduced to improve grid stability in high-penetration PV systems.

Cybersecurity emerged as a growing concern in 2024, particularly in relation to the communication functions embedded in modern inverters. With regulatory frameworks tightening in many countries and regions, there is a possibility that market share may shift in favour of domestically manufactured or regionally certified products as compliance requirements evolve.

PV TRACKER

The market for tracking systems in utility-scale photovoltaic (PV) applications continued to grow in 2024. According to Wood Mackenzie (UK), global shipments of PV tracking systems reached 111 GW in 2024, representing a 20% increase compared to the previous year.

The USA remained the largest market for tracking systems, where adoption has become standard practice in utility-scale PV installations. It is estimated that tracking systems are now used in approximately 90% of large-scale PV projects in the country. As a result, USA.-based manufacturers hold a strong position in the global market. Nextracker (USA.) led global shipments in 2024, followed by Arctech Solar (China), GameChange Solar (USA.), PV Hardware (PVH) (Spain), and Array Technologies (USA.).

Beyond the USA., the tracking system market is also expanding in other regions. In India, rapid growth in utility-scale PV deployment is expected to make it the largest market for tracking systems in Asia. Adoption is also increasing in Saudi Arabia, supported by large-scale renewable energy initiatives. South American countries are likewise seeing a rise in the use of tracking systems, contributing to broader global market diversification.

credit : pexels-cristian-rojas-885349

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SOCIETAL IMPLICATIONS OF PV AND ACCEPTANCE

PV is bringing profound and undoubtedly long-lasting changes to modern society - with positive impacts across economic sectors, societies and the environment, it is a fundamental pillar without which the energy transition could not go ahead. As with all radical transformations, the acceptability – or even, the desirability – of the change is linked to perception of the attractivity or necessity of the change and understanding of the impacts it will bring. For photovoltaics, this covers subjects such as the number of jobs involved, the creation of new companies and the disappearance or transformation of others, the generation of new financial flows, the impact on the environment and local communities. Understanding these social aspects related to the development of PV is becoming essential for governments adding photovoltaics to increasingly ambitious clean energy targets.

In particular, as penetration rates increase and utility scale and building integrated systems become more visible in local communities some populations are becoming less accepting of PV, whilst in specific countries, organised resistance to PV, most commonly for ground mounted systems but sometimes for building applied systems, has become a reality despite a generally positive opinion from the general public. Tools that have been developed to improve local acceptation include encouraging or mandating participation of local inhabitants and First Nations in project development, financing and/or governance.

This chapter aims at providing key elements and indicators that can be used to promote the desirability of PV as an element of the energy transition while highlighting essential aspects that remain as sensitive points.

ACCEPTANCE OF PV DEPLOYMENT

Acceptance can be defined as the willingness of stakeholders to approve, support, and engage themselves in the energy transition. This acceptance is fuelled by a positive perception of the changes and decreased by negative inputs. In the early days of the development of PV, up until the European boom of 2007 - 2009, PV benefitted from an overwhelmingly positive image; it was developed with small scale distributed systems on roofs and was not a significant generator of revenue or tension.

Drops in acceptability have tended to come after boom growth - for example, in Spain in 2007-2008 the local feed-in tariff was so popular that PV developed so fast that local authorities cut support mechanisms, in fear of economic and budget consequences for the country. Other countries that stepped into the FiT policies have also experienced major market development followed by a rapid halt. The EU was the epicentre of PV development until 2011-2012, and this happened across a number of other European countries like Spain, France, Belgium, Czech Republic, Greece, Bulgaria and Romania.

Opposition in these contexts most often came from sectors that perceived photovoltaics as a threat: traditional utilities and energy sector majors for example, were unable to accommodate photovoltaics in their traditional business plans and pushed poorly informed authorities to put the brakes on PV development. The PV community had built its reputation on its environmental advantages and had not yet had to work on a broad social acceptance and was unable to work with governments to create healthy dialogue.

ACCEPTANCE OF PV DEPLOYMENT / CONTINUED

The most recurring arguments motivating a lack of social acceptance for PV depend on the country and the market segments, however common themes can be found including:

- Unappreciation of the physical appearance of PV systems in natural or heritage landscapes.
- Unfavourable opinions on the financial flows generated by PV systems (seen as either "profiteering" by individuals or multinationals profiting from local resources without contributing to local economies).
- Fear that toxic and/or rare materials are used in the manufacturing process with no possibility of recycling and/or that such materials may leach into the environment over time.
- Worries that PV will supplant crops and pose a risk to nutrition and food sovereignty.
- Opposition to ground mounted systems on the grounds of impacts to biodiversity and local environments.
- Concerns that developers will fail to take community sentiments or needs into account during system design
- Fear around quality and reliability issues (fire and electrical risks, resistance to storms...)

Where PV penetration rates are low, these issues seem to remain in the background and only become prominent as market penetration increases. For those countries/regions where they are present, the PV sector, independent or government agencies have organised communication and educational campaigns, made fact-checking tools available to debunk the more aggressive false claims against PV and created educational resources targeted to the general and specific publics. Communication campaigns tend to be targeted towards the general public, working to demonstrate best practices, illustrate community investment and governance, or even educate the public about their ability to participate and engage in planning and development processes.

SOCIO-POLITICAL AND COMMUNITY ACCEPTANCE

In many countries there is a gap between national socio-political acceptance and community acceptance. These are associated with relatively different concerns and should therefore be addressed separately.

National socio-political acceptance refers to the acceptance of a technology by politics, policy makers, key stakeholders and the public. It englobes how legal and regulatory frameworks are adapted to include PV and takes into consideration subjects as diverse as who carries the financial burden for support mechanisms and grid capacity, jobs, industry development and local content.

Socio-political acceptance is often lagging behind community acceptance in the early stages of PV development in a country.

Governments have demonstrated maturing levels of national socio-political acceptance through adapting planning legislation and procedures, reserving research budgets for community engagement or technology advancement, unrolling support for local jobs through deployment rules and local content. Examples include when Turkiye put a hold on PV development until it was coupled with local value creation. In France, indirect local content requirements have been used in tenders for years, and local BIPV products were eligible for a FiT bonus over 2022 and 2023 - and in 2024 the two gigafactory projects for local manufacturing were declared Projects of National Interest. In Australia, the Australian Energy Infrastructure Commissioner completed a Community Engagement Review and the government accepted, in principle, all findings and set up a schedule of Activities in July 2024 that include a Developer Rating scheme, changes to consultation obligations and increased obligations for community engagement in tender schemes. In the USA, there are specific budgets for research on community acceptance and opposition to solar (SEEDS).

Community acceptance is related to the acceptance by local stakeholders. It includes concerns over distributional justice (costs and benefits), procedural justice, and trust; NIMBYism (Not In My Backyard) sometimes occurs. It covers consideration of economic aspects: grid costs, Renewable Energy System (RES) fees, unequal access to PV, concentration of revenues between a limited number of big companies, social aspects (environmental, aesthetical impact), and specific opposition (e.g., farmers, hunters, lobbyists, etc). Countries with mature utility scale markets can experience local and/or organised resistance to utility scale systems, with multiple factors cited as reasons for opposition, from the sealing of permeable lands to conflict of usage with agriculture or biodiversity reservoirs (Austria, France, Spain, Portugal, Sweden, UK) - or even on the incompatibility of PV with the local cultural heritage (Italy). This opposition can be aimed at planning permits, but also become manifest in local planning regulations that restrict the siting of utility scale PV (USA, France, Italy, Netherlands). Mandatory profit sharing of added value with local residents (France) is one type of action that can be taken to improve community acceptance, as is giving neighbours and community members the ability to participate in siting and planning procedures and consultations.

Challenges related to the acceptance of PV, even if they are directly influenced by the political, economic, geographical, social context in which PV installations are being deployed, are fairly similar across different regions and countries. This calls for a higher collaboration between countries on this topic based on the sharing of experience and exchange of good practices.

ACCEPTANCE OF PV DEPLOYMENT / CONTINUED

COMMUNITY ENGAGEMENT

Stakeholder engagement is an important way to improve acceptance and accelerate deployment. Stakeholders run across the value chain, from research down to permitting, construction and use - with stakeholder involvement important in some key areas such as permitting, grid connection and investment. Tools to increase involvement include public consultations in permitting procedures, self-consumption (encouraging all citizens to become generators), energy communities and collective ownership, open participation in the elaboration of climate and energy transition policies and targets or the provision of guidance and educational tools to end users.

The ability of local residents and communities to be involved in the process of zoning for solar, siting solar projects and the permitting procedure is now widely recognised as a lever for increasing community acceptance of large-scale projects. Accordingly, many governments have ensured that public consultations of local residents and communities are an integral part of the permitting procedures for PV projects, including in Austria, Japan, USA, France, UK, Japan. In Australia, since 2024 Queensland requires both social impact assessment and community benefit agreements. In 2025, Chinese Taipei increased public consultation in permitting procedures for solar, whilst in Thailand the public was consulted on changes to regulations that would facilitate adding solar on buildings. In Europe, the European Union adopted a series of new and updated guidance documents in May 2024 aimed at improving and streamlining permitting procedures to accelerate the deployment of renewables. These guidelines, recognising the importance of public participation for greater acceptability, recommend that "the needs and perspectives of citizens, local authorities and societal stakeholders should be taken into account at all stages of renewable energy projects from policy development to spatial planning and project development, deployment and operation[1]. Where opposition has developed, or long consultative procedures have blocked projects, legislation can reduce community consultation, as in Canada (British Columbia) where changes to planning permits have exempted projects from environmental assessment and community consultation but also in the USA (New York) where local courts have allowed the state to authorise projects on land that goes against local zoning bans, reducing local control of system siting.

Citizen participation in energy communities or citizen investment and governance of solar projects is an important lever for both empowering residents and citizens to initiate projects but also maintain economic flows to local communities.

1 Commission Recommendation (EU) 2024/1343 of 13 May 2024 on speeding up permit-granting procedures for renewable energy and related infrastructure projects

Tools include involving citizens in energy planning and investment (Austria), government co-financing education and promotion of citizen investment, direct and indirect incentives for citizen governance in projects such as bonus points in tenders (France). Consequently, citizen investment is present in many countries such as Austria, Germany, France, Denmark, USA, Australia... where citizens can either participate in controlling the project or receive financial participations. In Europe, the consultation process for a Citizens Energy Package[2] was started in 2025 - the Package is intended to ensure that energy transition is a Just Transition, and both protect and empower consumers.

Information and guidance web platforms and brochures can be used to facilitate citizen engagement in self-consumption, guiding through administrative procedures or demystifying the technology and providing buyers guide. In Isael, a solar potential tool was made available in 2025 allowing citizens to map their rooftop potential (tools have existed for many years in the USA, Australia, and different countries in Europe). In Australia the Solar Consumer Guide is a government website to guide through the process from installing to monitoring after installation; it was expanded and updated in 2024. In the USA the Solar Energy Technologies Office of the Federal Energy Department hosts the Homeowner's Guide to Going Solar website with the same goals and individual states also provides guides; in Spain the Institute for the Diversification and Saving of Energy website guides users on energy communities and self-consumption; in France Photovoltaique.info is a government financed website providing guidance from planning to operations for both end-users and professional installers; in Singapore the Energy Market Authority website provides guidance on installation, payment schemes and selling excess electricity and includes a list of the qualified persons (architects or professional engineers) with the permissions to install a PV system.

More generally, involvement can be seen under various angles:

- Individual participation as the beneficiary of PV electricity: Prosumers are consumers producing part or all of their electricity with PV while maintaining grid connection. Countries with prosumers policies, especially self-consumption ones are described in chapter 3. Energy access in emerging countries has shown for a long time that the implication of the populations significantly increases the adoption of decentralized energy sources.

2.https://energy.ec.europa.eu/news/citizens-energy-package-commission-starts-consultation-process-2025-06-19_en?utm_source=chatgpt.com

ACCEPTANCE OF PV DEPLOYMENT / CONTINUED

- Individual participation as group actions for the development and use of PV electricity: Energy communities, and the specific case of solar communities are involving communities in producing and managing energy, allowing a higher involvement of stakeholders.
- Collectives and groups participating in the development of PV: Companies and utilities involved in the PV business are known to become advocates of the energy transition, as are local authorities that adopt PV as a tool in their climate change mitigation strategies.

CLIMATE CHANGE MITIGATION

The paragraphs below highlight some key factual elements that can be used to improve the perception of PV in general, on economic, social and environmental aspects.

Climate change has become one of the key challenges that our society has to overcome and PV is one of the primary solutions for reducing greenhouse gas emissions in the energy sector.

Global energy related CO_2eq emissions increased to 37 800 Mt in 2024, up 0.8% on 2023, (compared to 1.6% from 2022 to 2023). Increasing the share of PV in the grid's electricity generation mix can significantly reduce the emissions from power generation.

The global average carbon intensity of electricity was around 473 g CO_2/ kWh[3] in 2024 (down approximately 3% compared to 2023) whereas for 1 kWh produced by PV the CO_2 emitted, taken on a life cycle basis, can be as low as 15 g depending on technology and irradiation conditions - the IEA PVPS Task 12 indicates that a system in Italy mono-axial solar trackers and annual irradiation of 1 820 kWh/m^2/y will have a carbon intensity of 17.1 g CO_2eq/kWh (or 20.7 g CO_2 eq. /kWh if the modules are at fixed angle of 34°).

The total CO_2 emissions that are avoided by PV on a yearly basis can be calculated considering the amounts of electricity that can be produced annually by the cumulated PV capacities installed at the end of 2024 and considering that these amounts replace equal amounts of electricity that would be generated by the respective grid mixes of the different countries where these PV capacities are installed.

3. EMBER indicates a global average of 473 gCO2/kWh in their Global Electricity Review 2025; the IEA indicates 445 gCO2/kWh in 2024 in their Electricity 2025 report.

The annually produced PV electricity is calculated based on country-specific yields depending on the average yields of PV installations and irradiation conditions in each country. The inherent emissions of PV installed since 2022 has been uniformly considered as monocrystalline China-manufactured modules, independently of the country of installation. As PV penetration rates increase, PV production increasingly replaces electricity with a CO_2 content of the countries average grid mix (in the past, the CO_2 content of marginal production would have been considered is PV only replaced peak generation). This significantly reduces the "avoided" CO_2 as a whole, as PV now replaces average electricity, not just the most polluting, easily dispatched electricity. However, as penetration rates grow, the total volume of electricity displaced increases, with net benefits. Conversely, this calculation does not consider curtailed volumes of PV.

CO_2 avoided

1 045 MT CO_2eq

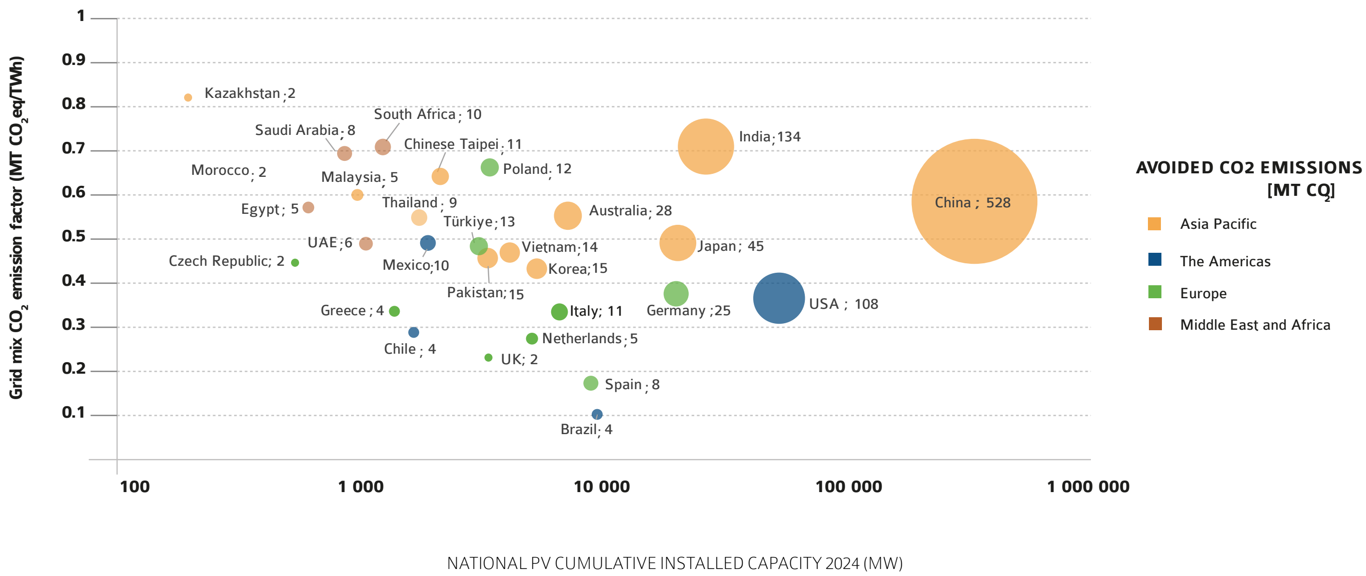
Using this methodology, calculations show that the PV installed capacity today avoids up to 1 045 million tonnes of CO_2eq annually. Thus, it avoids approximately 2.8% of the energy sector emissions. This is essentially due to the fact that PV is being massively installed in countries having highly carbon intensive grid mixes, such as China, India, Australia, Japan and Poland.

Figure 5.1 gives a view of the avoided CO_2 emissions in the first 30 countries in ranking of avoided CO_2 emissions, and which represent in total over 98% of global avoided emissions. This figure displaying the countries as a function of their installed PV capacities and grid mix carbon intensities clearly shows their differential contribution to the global avoided emissions and the high impact of their respective grid mix compositions. The more CO_2 the power mix in a country emits, the more positively PV installations will contribute to avoiding emissions; the more PV is installed, the lower the grid mix's emissions each year.

Pakistan is a notable entry to the club of countries with solar having a significant impact on energy sector emissions (Figure 5.2). Because a large share of Pakistan's electricity was already low carbon (hydro), the introduction of massive amounts of solar in 2024 has displaced more costly gas/fossil generation (the overall grids carbon content did decrease by approximately 5%) and allowed residential clients to increase their consumption without increasing the grids CO_2 content.

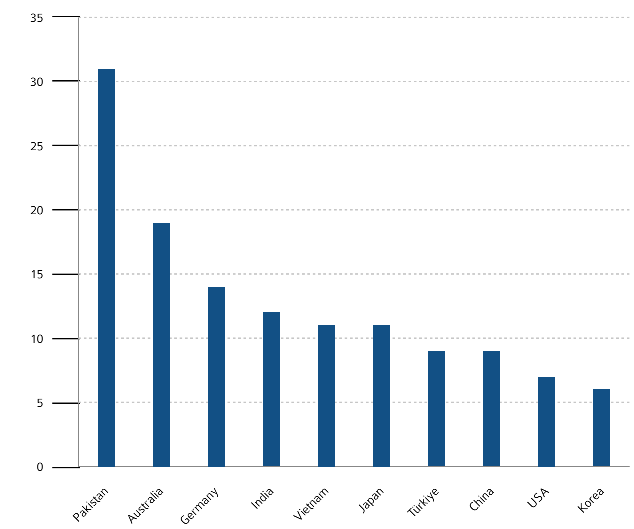
CLIMATE CHANGE MITIGATION / CONTINUED

FIGURE 5.1: CO_2 EMISSIONS AVOIDED BY PV



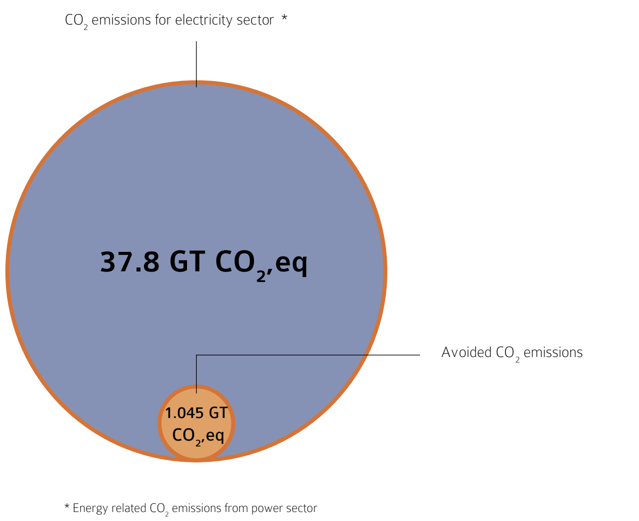
SOURCE: IEA PVPS & OTHERS

FIGURE 5.2: AVOIDED CO_2 EMISSIONS AS PERCENTAGE OF ELECTRICITY SECTOR TOTAL EMISSIONS



SOURCE: IEA PVPS & OTHERS

FIGURE 5.3: AVOIDED CO_2 EMISSIONS AS PERCENTAGE OF ENERGY SECTOR TOTAL EMISSIONS



SOURCE: IEA PVPS, IEA, EMBER & OTHERS

VALUE FOR THE ECONOMY

The turnover of the PV sector in 2024 is estimated to have amounted to a minimum of 430 billion USD (estimated here) to as much as 520 billion USD (REN21/BNEF). Here, this number has been calculated based on the size of the PV market (annual installations and cumulative capacities) and the average price value for 2024 for installation and Operation & Maintenance (O&M) specific to the different market segments and countries, supplied by IEA PVPS member countries. With nearly 60% of new capacity additions in China, the overall value for the global economy is largely dependent on the value generated in China – and the first approach methodology used here, based on annual average cost data in a year of changing prices is not meant to represent an in-depth study, but a first approach.

Given the variety of existing maintenance contracts and cost, the turnover specifically linked to O&M has not been considered in detail. However, the global turnover related to O&M was estimated at around 20 billion USD per year. This estimate can be considered as a lower range value, due to the assumptions made for its calculations. It does not take into account either the material cost of replacement and repowering, which is hardly visible, or the value of recycling. O&M costs have decreased over time and a part of PV systems are not maintained through regular contracts (especially residential roof-top systems, unless they are monitored).

Whilst the growth of the market and changes in cost meant that the annual market increased significantly in value from 2022 to 2023, smaller market growth ("just" 30%) and increased drops in prices have meant that the annual market increased slowly from 2023 to 2024 at approximately 430 billion USD - despite steady growth in expected O&M business value increasing to 20 billion USD,

Turnover PV

430 Billion USD

O&M

20 Billion USD

Global business value

+ 7% in 2024

For the purposes of this report, the value of the PV sector for the economy has been assessed based on the volume in MW of installations rather than by evaluating all the contributions of the complete value chain. The assessment of the business value of the industry is in general more complex, due to the decentralized production and the existence of transnational companies. However, a specific approximation of the industrial business value of PV was performed for IEA PVPS major PV manufacturing countries and is presented in a specific section below.

CONTRIBUTION TO THE GDP

Figure 5.4 shows the estimated business value of the PV sector in IEA PVPS reporting countries as compared to their national GDPs.

These values were determined based on the internal PV markets in each country, as described above, and hence they do not take imports or exports into account. Some countries benefited from exports that increased the business value they obtained through the internal PV market while huge imports in other countries had the opposite effect. However, as already mentioned, the market is integrated to the point that it would be extremely complex to assess the contribution from each part of the PV value chain.

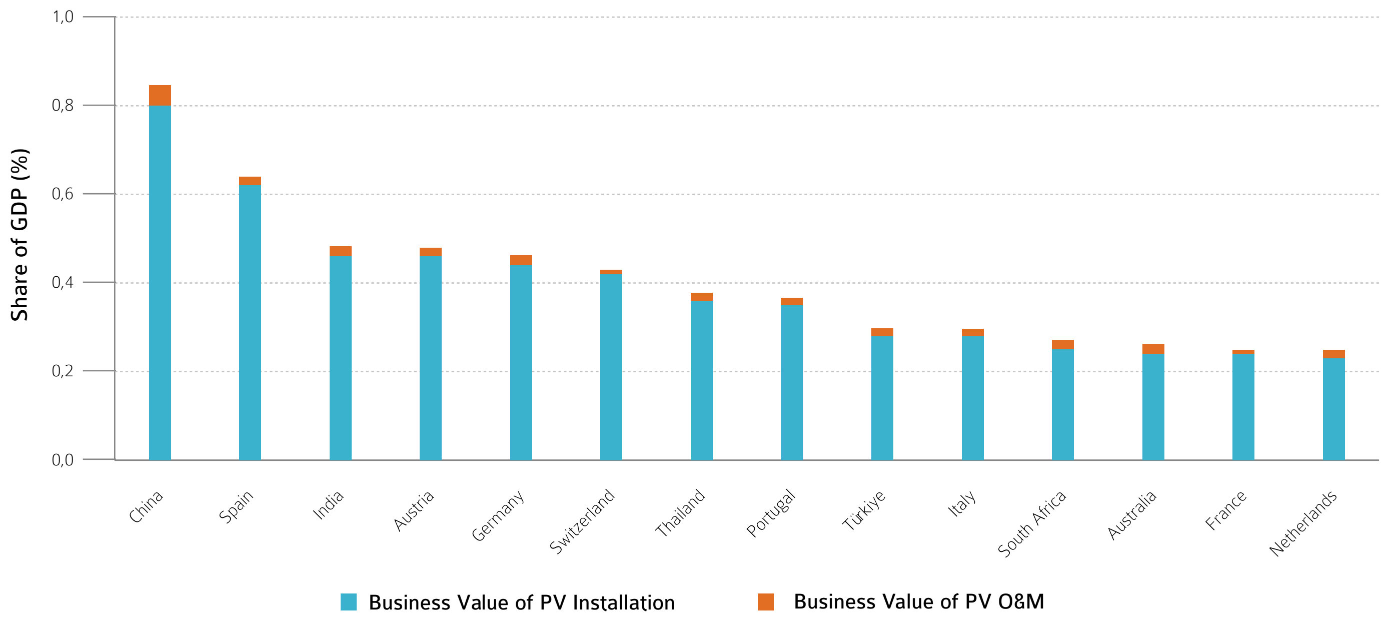
The business value in national markets depends both on the market and segment size and local prices; despite the drop in prices, it has still grown in China, as well as in countries with ballooning markets. In the selected IEA PVPS countries (major markets), the share of Business Value of the market in terms of GDP grew in France, the USA, China, Japan and Italy, whilst in absolute value, in addition to these countries it also grew in Portugal. Not shown, both Pakistan and Brazil had a measurable share of GDP represented by the Total Business Value of PV, and although value estimates are rough, in absolute values both of these markets were large enough to bring them into the Top Ten most valuable markets in 2024.

On a global scale, PV business value represents around 0.38% of the GDP, slightly down on 2023 values but still well up from 0.25% in 2022. compared to around 2.9% for energy investments in 2024.

This level of investment remains significative on a global scale but is still well below the estimated 1 116 billion USD of global investments in fossil fuels in 2024.

VALUE FOR THE ECONOMY / CONTINUED

FIGURE 5.4: BUSINESS VALUE OF THE PV MARKET IN 2024 IN SELECTED IEA PVPS COUNTRIES AS SHARE OF GDP %



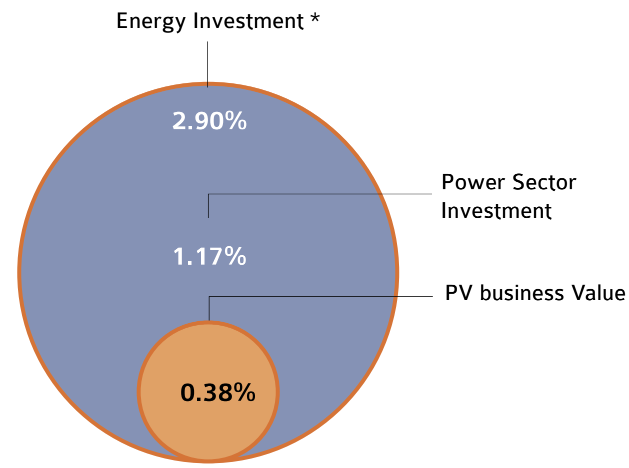
SOURCE IEA PVPS & OTHERS

TABLE 5.1: TOP 10 RANKING OF PV BUSINESS VALUES IN SELECTED IEA PVPS COUNTRIES

RANK	COUNTRY	BILLION US$
1	CHINA	158.5
2	USA	60.0
3	GERMANY	21.8
4	INDIA	19.1
5	SPAIN	10.9
6	JAPAN	8.1
7	FRANCE	7.9
8	ITALY	7.1
9	AUSTRALIA	4.7
10	SWITZERLAND	4.0

SOURCE IEA PVPS & OTHERS

FIGURE 5.5: CONTRIBUTION TO GLOBAL GDP OF PV BUSINESS VALUE AND ENERGY SECTOR INVESTMENTS



* Power sector

SOURCE: IEA PVPS & OTHERS

VALUE FOR THE ECONOMY/ CONTINUED

INDUSTRIAL VALUE OF PV

Even though assessing the detailed contributions of the different parts of the whole PV value chain is hardly possible in this report due to the level of integration of the market, an approximate evaluation of the industrial business value of PV has been performed and the results detailed for IEA PVPS major PV manufacturing countries.

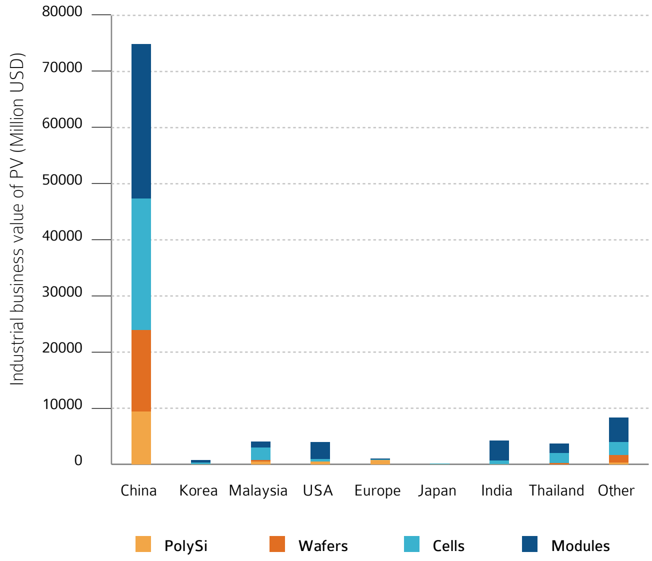
The evaluation was made based on the production volumes and manufacturing shares of countries for polysilicon, wafers, cells and modules, including thin film technologies, as detailed in Chapter 4, as well as on an average estimated price for each of these four segments. The prices taken into account are based on average prices reported in member countries. We consider that equipment and materials are included in this computed value. BoS, including inverters are not considered here.

The estimated global industrial value of PV established itself at around 100 billion USD in 2024, down from 104.7 billion USD in 2023. This drop is due to the significant price drop in average module and system costs in China (dropping below 0.09 USD/W). Figure 5.6, 5.7 and 5.8 show for major PV manufacturing countries the estimated contribution of each step of the value chain in the PV industrial value for each country in absolute and relative terms as well as the comparison of this value to their GDP.

China is by far the predominant manufacturing country in all steps of the PV value chain, with an approximate share of 0.4% of its GDP (down from 0.46% in 2023) represented by the PV Industry (polysilicon, wafers, cells and modules). As in previous years, despite much lower production volumes, the PV industry in Malaysia represents a significantly higher share of the country's GDP compared to China, stable at between 0.9% and 1%. Similarly, in Thailand the PV industry represents 0.7%. As planned projects in the USA and India come online, the share in these countries will become more visible - as can be seen in 2024 for India.

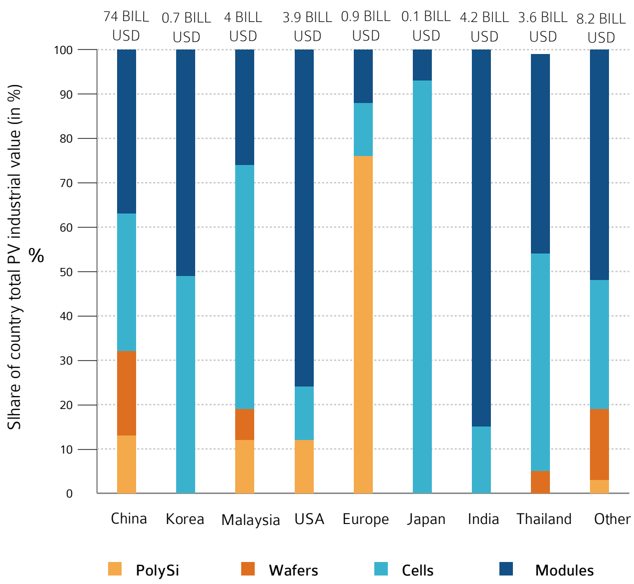
For the BoS, the industry is significantly more distributed, and production occurs in many countries. It is not counted as such here, with many local manufacturers and suppliers servicing the PV industry present across the world in cabling, supports and electrical protections; an analysis would make sense to grasp the extent of the PV industry impact on the countries' economic landscape but is not within the scope of this report.

FIGURE 5.6: ABSOLUTE PV INDUSTRIAL BUSINESS VALUE (MILLION USD) IN 2024



SOURCE IEA PVPS & OTHERS

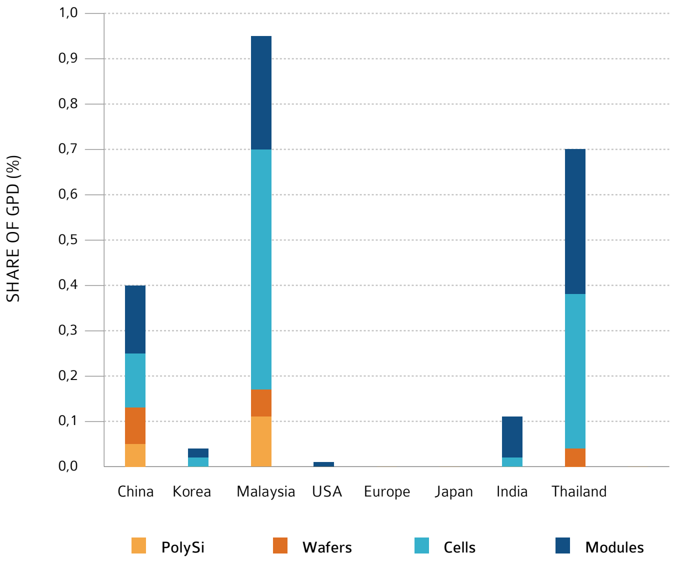
FIGURE 5.7: PV INDUSTRIAL BUSINESS VALUE ALONG THE VALUE CHAIN IN 2024



SOURCE: IEA PVPS & OTHERS

VALUE FOR THE ECONOMY / CONTINUED

FIGURE 5.8: PV INDUSTRIAL BUSINESS VALUE AS SHARE OF GDP IN 2024



SOURCE: IEA PVPS & OTHERS

PV sector employed an estimated

9.1 million people in 2024

SOCIAL IMPACTS

EMPLOYMENT IN PV

Figure 5.6 gives an overview of the total direct full-time equivalent jobs in IEA PVPS countries and other major markets. Reported numbers have been established based on the IEA PVPS National Survey Reports and additional sources such as the IRENA jobs database. It should be noted that these numbers are strongly dependent on the assumptions and field of activities considered in the upstream and downstream sectors and represent an estimate in the best case and will diverge with those reported in other sources for this reason.

The methodology used takes data provided by reporting countries on the upstream (industrial) and downstream (distributed and utility scale PV installation and O&M) job numbers, then extrapolates to other markets depending on their respective market specifics. A distinction is made between countries in developed economies having a costly, low intensity work market and the emerging economies with an affordable work force, as well as economies somewhere between these two, where labour costs are midrange. Manufacturing numbers are based on industry reports and additional sources and split according to the same methodology. Installation numbers are always an approximation.

This report estimates that the PV sector employed in the order of 9.1 million people globally at the end of 2024. An estimated 2.8 million were employed in the upstream part, including materials and equipment, while 6.3 million were active in the downstream part, including O&M.

As the leading producer of PV products and the world's largest installation market by a long margin, China is markedly leading PV employment with around 6.5 million jobs in 2024, which corresponds to a significantly higher number of jobs than anywhere else. Lower by one order of magnitude, India, Brazil, the USA, and Pakistan follow, with between 225 000 and 375 000 FTE (Full Time Equivalent). There are an estimated 500 000 FTE in the European Union. Other countries with large workforces included Türkiye, Malaysia, Thailand, although estimations are difficult. Japan has a steady PV market but lost a number of jobs, dropping to approximately 60 450 jobs in 2024.

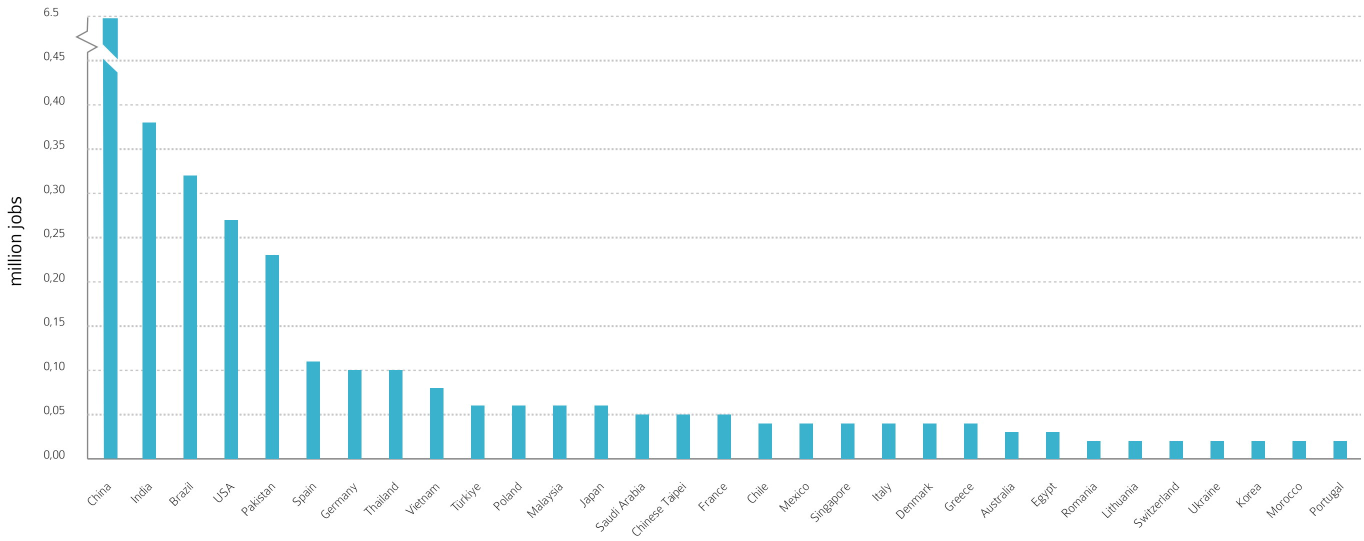
Generally, in good correlation with the market evolutions, PV employment expanded where the market developed. As the scale of manufacturing increases, so too does automation, reducing the job intensity per GW in the manufacturing sector. On the other end of the spectrum, residential (distributed) PV deployment has the highest job intensity along the value chain – although it varies significantly in intensity/MW between developing countries and developed countries.

When specifically focusing on development and installation activities, more labour intensive than manufacturing, on average the job intensity ranges from 3 FTE/MW for utility scale PV in developed countries (with some countries dropping below 2 FTE/MW as automation and the use of robots increases) with established markets, to up to 20 FTE/MW for distributed systems in developing countries. O&M generates many manual jobs while the entire PV value chain creates good quality jobs, from research centres to manufacturing.

With an estimated total of 9.1 million jobs in the solar PV sector worldwide in 2024, PV employs well above one third of the total renewable energy workforce and remains number one in the employment ranking of the global renewable energy sector, as new solar capacity additions largely outnumber other renewables sources, this is not expected to diminish.

SOCIAL IMPACTS / CONTINUED

FIGURE 5.9: GLOBAL EMPLOYMENT IN PV PER COUNTRY



SOURCE IEA PVPS & OTHERS

Established manufacturing is a major source of jobs in photovoltaics in China, Vietnam, Thailand and Malaysia, whilst the increase of capacity in the USA, India and Türkiye are increasing manufacturing jobs in these countries. Manufacturing jobs are at risk in Europe as manufacturing projects have been put on hold although major factories planned for France may reverse the tendency in the coming years.

IMPACT ON ELECTRICITY BILLS

The impact of developing PV on electricity bills works through three separate mechanisms; the cost of support mechanisms; the cost of electricity on wholesale markets and the cost of grid access fees.

Whilst in the past these three elements were seen as burdens, the increasing competitivity of photovoltaics and the fluctuations of wholesale electricity costs over the past 3 years can allow one to consider them as opportunities:

Firstly, PV is reimbursing its support mechanisms: the impact of the increase in gas prices resulting from sanctions due to the war in Ukraine over 2022 and 2023 has resulted in PV (and other renewables) playing a much greater role in security of supply than intended so far. With spot market prices skyrocketing across Europe due to record high gas process, PV suddenly become not only competitive but desirable from an economical point of view. Those countries running support mechanism on Contracts for Difference even generated positive cash flow for governments, as renewable generators sold high on the market but reimbursed the state to reach agreed on contract levels for each MWh generated. In the UK, France, solar CfD contracts funnelled back millions of dollars to governments in 2022 (when market costs were exceptionally high) and in 2023 - despite market caps and reforms and lower market costs) in France, support mechanisms for solar raised 724 million euros (761 million USD) in 2022 and a further 81.3 million euros (88.9 million USD) in 2023 for the government and allowed the government to reduce taxes on electricity to contain prices for consumers. In Austria, fees to finance support mechanisms collected in electricity bills were cancelled in 2022. In the ACT in Australia, CfD contracts limited consumer electricity price to below inflation raises, under 5%, compared to a national average of over 20% in 2023/2024.

Secondly, PV electricity generation is being sold on the markets in quantities sufficient to reduce market costs, especially in countries where peak consumption is concordant with solar generation. PV reduces wholesale market prices for electricity at the time of production – negative prices illustrate this and are most often seen when high solar (or wind) generation occurs at low load times. Most of the Western European electricity markets saw an increase in the number of hours of negative or close to zero prices in 2024 (doubling in some market zones) including Spain for the first time, with similar events in the USA, and China (in Australia the number of negative hours decreased in some states (Queensland) but increased in others). The savings for electricity consumers and the society, in general, is difficult to compute but most studies conclude on significant savings and additionally, cost decrease in the distribution grid up to a certain penetration of PV.

Thirdly, solar, generally combined with batteries, has demonstrated its ability to provide key network stability services cheaper than fossil fuel plants can - for example, in the nuclear-reliant France, delayed maintenance of the nuclear portfolio in 2022 led the transmission grid manager to call on renewables to step up in supplying services necessary to the grid, in particular voltage stability - whilst coal, heavy oil and additional gas facilities could have supplied theses services, renewables were by far the most economical, and climate friendly, solution. In Australia, big batteries supply frequency control ancillary services (55% in Q4, up from 53% in 2023) as well as energy sales; the sale of energy from big batteries increased markedly in 2024 on the Australian market as high spot price volatility provided favourable conditions. In the USA, solar power plants across several different states and extreme weather events have been key generators during crises.

PV FOR LOW INCOME RELIEF

Besides its direct value for the economy and the jobs that it creates, both making contributions to the prosperity of the countries in which it is being installed and manufactured, PV entails additional positive implications on the social level if leveraged with appropriate policies.

PV can be a competitive alternative to increase energy access in remote rural areas not connected to power grids. Improved energy access can benefit rural business performance, free up workers' time, provide more studying hours for children, improve health through cleaner cooking, and create or enhance jobs as a result. Electrification is a key factor to reduce poverty and increase education, with a direct impact on women's and children's life standards in many regions in the world. In that respect, PV would deserve a significant attention for electrification.

PV can also assist low-income households and communities in managing electricity needs, even in countries with stable electricity networks and close to total electrification. Programs to assist low-income families to install grid connected solar, either through means tested rebates, loans or gifts from state agencies or private organisations have been developed on national (Australia, Italy, Korea, USA, UK), state, and local levels.

The development of energy communities is also being used as a tool to provide cheaper solar electricity to in need consumers in some countries such as Italy, Portugal. With the combination of high and volatile electricity prices experienced across many countries in the past 3 years, self-consumption of increasingly cheap solar is more and more often seen as the best solution to maintaining electricity bill affordability.

PV FOR EMPOWEREMENT OF FIRST NATIONS COMMUNITIES AND RECONCILIATION

The development of utility scale PV in remote or sparsely populated areas has been accompanied by discussion on local acceptability, energy injustice, and the risks of recreating the exploitative nature of mining, with profits flowing to outside investors and low benefit sharing with locals, and in particular with First Nations (indigenous) peoples.

Land-rights safeguards, benefit and profit sharing and frameworks for participation in equity and governance have emerged in several countries, sometimes with programmes to subsidies or facilitate access to competitive tenders when local participation is guaranteed.

Initially focused on rural electrification through off-grid and hybrid systems in First Nations communities - such as those supported by the USA Department of Energy's Office of Indian Energy Policy and Programs since 2005 - policies have since evolved to explicitly promote clean energy access for these communities. Canada's 2018 Federal Clean Energy for Rural and Remote Communities Program is a key example. More recently, emerging frameworks have widened to cover national energy transition strategies, with a stronger emphasis on First Nations leadership and equity, as demonstrated in Australia's 2024 National First Nations Clean Energy Strategy.

Participation in equity and governance of utility scale plants, or significant levels of co-design has become a key trend as First Nations push for more than conciliatory consultation.

In Australia, the First Nations Clean Energy Strategy was published in 2024; it aims to provide a framework to ensure that "governments, industry and community members... work together to create opportunities for First Nations people to make their own choices and gain social and economic benefits through the energy transition.". Actions plans will be developed and should cover subjects as wide as regulatory protection, skills development, business opportunities and better access to SIV 's, investor forums, and the creation of a specific investment fund. Precursor initiatives include the First Nations Clean Energy Network created in 2021. The network provides support, tools and information to accelerate participation. Ongoing projects include the 300 MW Yoorndoo

SOCIAL IMPACTS / CONTINUED

Ilga Solar where the Barngarla People have freehold ownership of the land and the 10 MW Junja Solar Farm where First Nations have partial ownership and local companies will be contracted for construction works.

Canada's Indigenous Loan Guarantee Program, launched in 2024, provides federal support for equity investment in major energy and natural resource assets, including clean energy. As noted by First Nations leaders during a 2025 CanREA panel, land access, consent, and equity are now preconditions to project success - and programs such as the Smart Renewables and Electrification Pathways program (SREPs) Indigenous-Led Clean Energy (ILCE) stream are making this explicit. Ongoing projects with important First Nations participation include the 20 MW Duchess Solar system (majority ownership), the Ulkatcho First Nation 3.8 MW Yukon system or the already built 4.8 MW Salay Prayzaan Métis Crossing Solar Project.

In the USA federal policy looks to fostering tribal energy sovereignty, capacity-building, and economic empowerment through a range of targeted financial mechanisms. The EPA's Solar for All program allocated part of its USD 7 billion clean-energy grants specifically to tribes, supporting ground-mounted solar-plus-storage systems for low-income Native households (e.g., Chippewa Cree and Oglala Sioux Kickoffs). The DOE, through its Bipartisan Infrastructure Law funding (~USD 366 million for tribal & rural communities), is scaling up solar microgrids for hundreds of Navajo and Hopi homes and community facilities. Building long-term project pipelines, the Alliance for Tribal Clean Energy Fund raised USD 30 million for pre-development efforts, supporting feasibility studies and environmental assessments for future 2 GW to 6 GW-scale tribal PV installations. The Inflation Reduction Act (IRA) improved tribal solar finance by allowing non-taxed tribal entities to access direct-pay Investment Tax Credits (ITC) up to 70%, with bonus rates for tribal land, domestic content, and energy communities. This enabled large-scale projects such as Kayenta (55 MW) and Red Mesa (94 MW) by the Navajo Tribal Utility Authority.

The use of renewable energies as a tool for reconciliation has been integrated into the communication strategies for some programs; however, a 2021 study, "Reconciliation through renewable energy? A survey of Indigenous communities, involvement, and peoples in Canada[1]" concluded that it was not clear that practices were leading to real reconciliation.

The study indicated that in the past, benefit sharing agreements tended to provide small, and temporary benefits; resource revenue sharing agreements had longer term benefits, whilst equity and governance participation was recognised as important by indigenous communities "for the increased delivery of social goods, and local regional development; reduced ecological impacts; accelerated permit approvals; reduced risk/lower cost of capital and long-term stable revenue". The study indicates that some "equate equity ownership with reconciliation". However, this study also noted that, at that time, of 194 projects only 41 were controlled by Frist Nations or indigenous communities, and most of these on community-controlled land.

BEST PRACTICE PRINCIPLES FOR CLEAN ENERGY PROJECTS WITH FIRST NATIONS:

1. Engage respectfully
2. Prioritise clear, accessible and accurate information
3. Ensure cultural heritage is preserved and protected
4. Protect country and environment
5. Be a good neighbour
6. Ensure economic benefits are shared
7. Provide social benefits for community
8. Embed land stewardship
9. Ensure cultural competency
10. Implement, monitor and report back

In Australia, energy providers and stakeholders have developed Innovate Reconciliation Action Plan's. These plans tend to share several core commitments covering building relationships, deploying cultural awareness training, and respect for cultural heritage and Country. Empowerment through procurement and employment and reconciliation working groups are also common. The First Nations Clean Energy Network developed a set of Principles[2] that have been adopted more widely.

1. Christina E. Hoicka, Katarina Savic, Alicia Campney, "Reconciliation through renewable energy? A survey of Indigenous communities, involvement, and peoples in Canada", Energy Research & Social Science, Vol 74, 2021, https://doi.org/10.1016/j.erss.2020.101897

2. Best Practice Principles for Clean Energy Projects, First Nations Clean Energy Network; https://assets.nationbuilder.com/fncen/pages/183/attachments/original/1680570396/FNCEN_-_Best_Practice_Principles_for_Clean_Energy_Projects.pdf?1680570396

PV END-OF-LIFE

The volume of PV modules reaching the end of their useful (first) lifetime is still marginal compared to the volumes of new PV modules deployed in the market. However, as the PV market develops fast and often faster than anticipated, the same trends are expected to be witnessed for end-of-life PV module streams. Forecasting precisely end-of-life PV module streams is a complex exercise for several reasons. PV modules may reach the end of their useful lifetime for different reasons - significant performance degradations, premature failures from production defects, damages from transportation and installation or premature dismantling related to insurance claims, repowering, or revamping. These modules then enter end-of-life streams anywhere from after just one year or up to thirty years or more. A large disparity in useful lifetime is observed between distributed and centralized applications, with shorter useful lifetimes observed in centralized systems, mostly driven by economic considerations, i.e. the hardware is uninstalled due to financial lifetimes and not technical failures. The market for second-life PV modules is a further source of uncertainty in end-of-life PV module streams forecasts.

Depending on the country and region, end-of-life PV modules may be treated under PV-specific regulations or under general waste and disposal-related regulations.

In the EU, end-of-life PV module streams are regulated by the WEEE (Waste Electrical and Electronic Equipment) Directive since 2012. The Directive is based on the extended producer responsibility principle that stipulates those producers (the term broadly refers to manufacturers, distributors, sellers and importers) placing PV modules on the EU market (regardless of where the PV modules were manufactured) are liable for the costs of PV waste collection, treatment and monitoring. Producers can choose to operate their own take-back and recycling scheme or join existing ones. The WEEE Directive sets collection, recovery and preparation for reuse and recycle minimum requirements, which are expressed in percentage by mass.

Recycling requirements are currently typically achieved through mechanical processes which:

1. rely on removal of some components (e.g., frame, junction box, cables),
2. mechanical shredding,
3. sorting into different material categories, taking advantage of physical property differences (weight, conductivity, density,...) amongst the recovered materials (plastics, glass, metals).

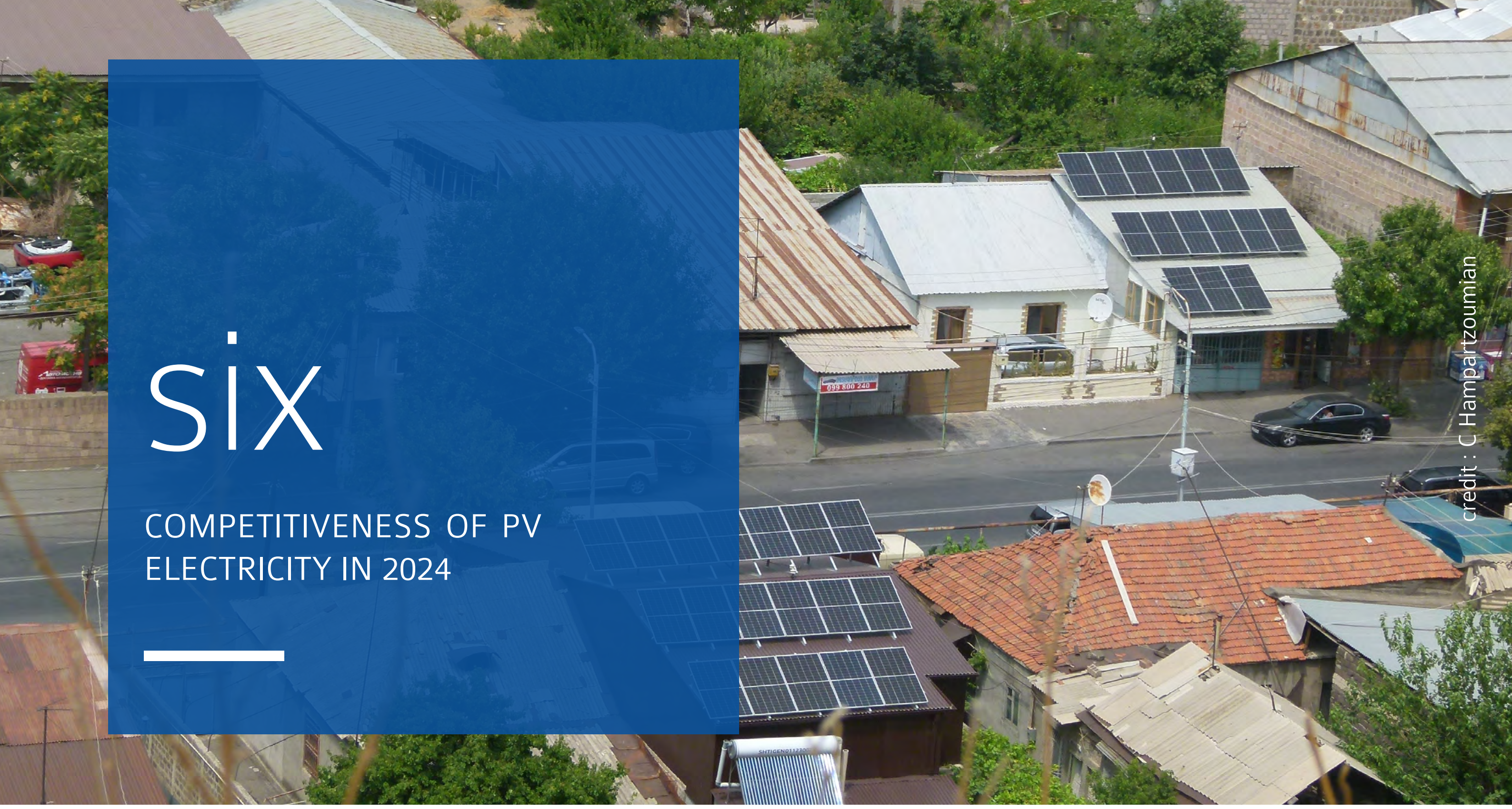
These mechanical recycling processes are usually performed by incumbent recycling actors (e.g., EEE recyclers, metal recyclers, glass recyclers) who leverage existing recycling facilities, equipment and expertise, eventually reaching recycle at a relatively low net cost while enabling WEEE-compliant recovery rates. Processes based on delamination (mechanical delamination (e.g., hot-knife) or thermal delamination (e.g., pyrolysis, incineration)) also exist and are implemented at a commercial level in some rare cases only.

Combined with some subsequent chemical process, such recycling routes have the potential to recover materials with higher levels of purity (e.g., glass, silicon) or to recover high-value or critical materials (e.g., silver). However, they are associated with higher net costs and the WEEE Directive requirements are not stringent enough to provide a regulatory push for such processes.

In other regions, country specific approaches have been taken. In Asia, in China, two demonstration lines for PV waste recycling were set up after a 2019-22 national R&D program focused on recycling crystalline silicon PV modules, and in April 2022 the PV Recycle Industry Development Center in Jiaxing, Zhejiang province was set up as a public institution affiliated with the Ministry of Industry and Information Technology. In Australia, in some states, PV modules are banned from landfill and must be treated in the electronic waste streams. Limited facilities exist to undertake recycling; however a Solar PV Stewardship pilot project was opened first for decentralized PV waste and then utility scale waste in 2024.

In Japan, from July 2022, setting aside of future cost of EoL PV systems became compulsory for solar power generation facilities with more than 10 kW installed capacity under the FIT program. Owners of PV systems who fail to make reserves for dismantling and removal of PV modules may be subject to revocation of FIT. The Organization for Cross-regional Coordination of Transmission Operator, OCTT, is responsible for managing the reserves. Part of the reserve is expected to cover the cost of recycling of PV modules. In September 2021, the Agency for Natural Resources and Energy under the Ministry of Economy, Trade and Industry published a guideline.

In the USA by early 2024 there were nearly 30 recyclers listed in an Office of Energy Efficiency & Renewable Energy website, built as part of the National PV Recycling Program founded in 2016. Thin film cadmium-telluride panels, which represent a smaller part of the solar market, undergo a specific recycling process with a USA manufacturer running dedicated recycling facilities for thin film panels which recover the semiconductor material (cadmium and tellurium) in addition to glass and copper. The Inflation Reduction Act also contained limited incentives for the construction of recycling facilities for renewable energy technology, and several announcements of recycling facilities have been made since its passage in August 2022.



six

COMPETITIVENESS OF PV ELECTRICITY IN 2024

The rapid price decline that PV experienced in the last years has already opened possibilities to develop PV systems in many locations with limited or no financial incentives. However, the road to full competitiveness of PV systems with conventional electricity sources requires answering many questions and bringing innovative financial solutions, especially to emerging challenges.

This section aims at defining where PV stands regarding its own competitiveness, starting with a survey of module and system prices in several IEA PVPS reporting countries. Given the number of parameters involved in competitiveness simulations, this chapter will mostly highlight the comparative situation in key countries. Prices are often averaged and should always be looked at as segment related.

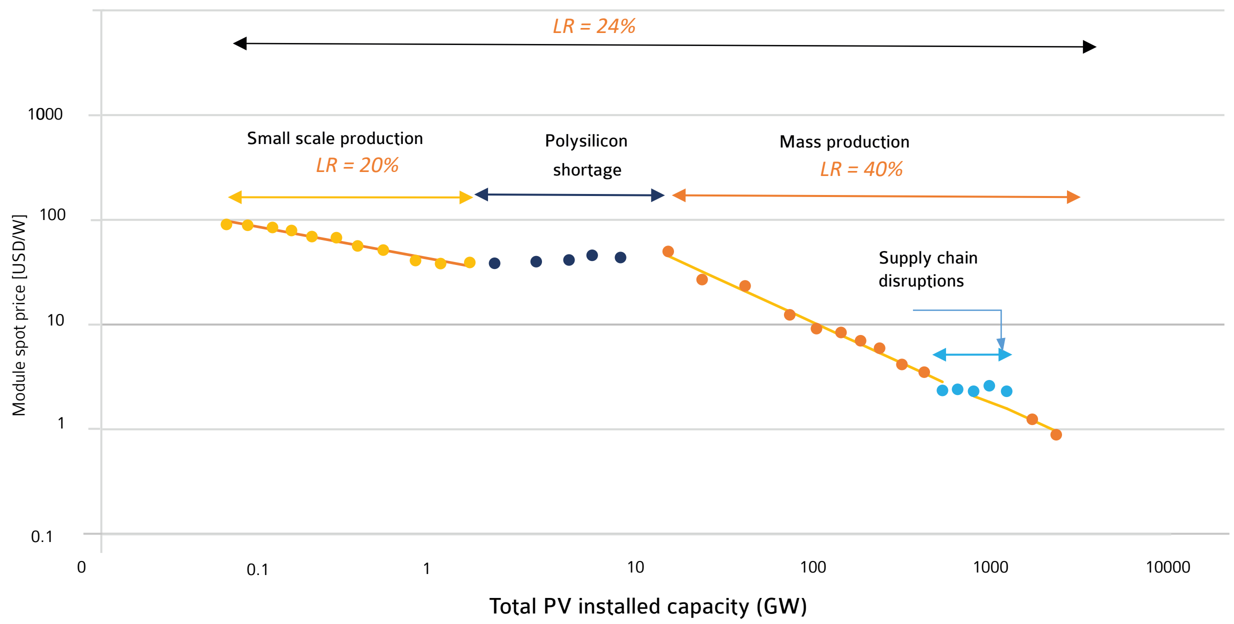
The question of competitiveness should always be contemplated in the context of a market environment created for conventional technologies and sometimes distorted by historical or existing incentives. The fast development of nuclear in some countries in the last 40 years is a perfect example of policy-driven investments, where governments imposed the way to go, rather than letting the market decide. The oil and gas markets are also perfect examples of policy-driven energies which are deemed too important not to be controlled. PV competitiveness should therefore be considered in this same respect, rather than the simple idea that it should be considered competitive without any regulatory or financial support. There are also further barriers, other than economic, for PV to become the obvious alternative to coal (rather than gas) for utilities. Currently, many already unprofitable coal power plants are still in operation because the regulatory and financial structure is not tailored for so many coal units to become stranded assets. In addition, the choice of alternatives to coal is frequently not motivated by pure economics but is biased towards an electricity price and market design that favour gas-fuelled electricity. Since all sources of electricity have benefited at some point from such support, the question of the competitiveness of PV should be considered carefully. Hereunder, we will look at the key elements driving the competitiveness of PV solutions.

MODULE PRICES

The very first period of PV market development can be considered starting from the first prototypes to small-scale production leading to a total PV installed capacity of around 2 GW. During this first phase, price reductions corresponding to a learning rate of 20% were achieved: this allowed the total PV installed capacity to continue growing further. At that point, prices stabilized until the total capacity reached around 10 GW: this period is known as the time of low availability of polysilicon that maintained prices at a high level. Then, a third period started which is still the case today, beginning with the mass production of PV, especially in China. During this period ranging from 10 GW to current levels, significant economies of scale have led to a learning rate of 40% - the supply chain disruptions due to COVID having slowed it slightly. The present price drops due to overcapacity have compensated in part for the stable prices in the post-covid period. In a few years it will be possible to better evaluate the impact of the significant manufacturing capacity increases that occurred in 2023 and 2024.

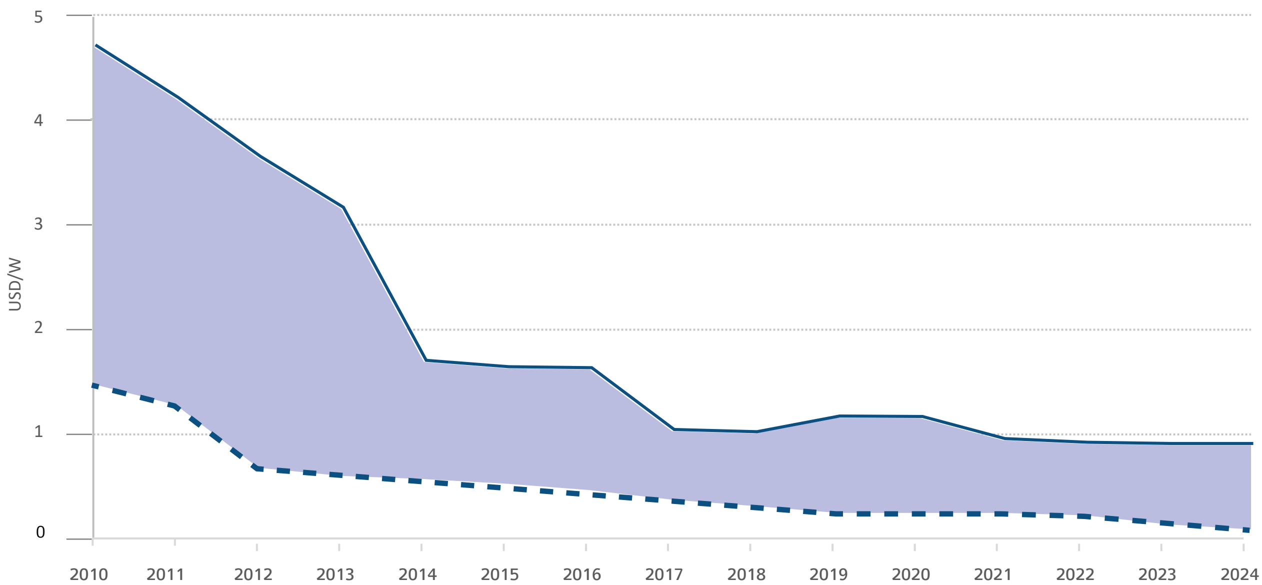
MODULE PRICES / CONTINUED

FIGURE 6.1: PV MODULES SPOT PRICES LEARNING CURVE (1992-2024)



SOURCE IEA PVPS & BECQUEREL INSTITUTE

FIGURE 6.2: EVOLUTION OF PV MODULE PRICES RANGE IN USD/W



SOURCE IEA PVPS & OTHERS

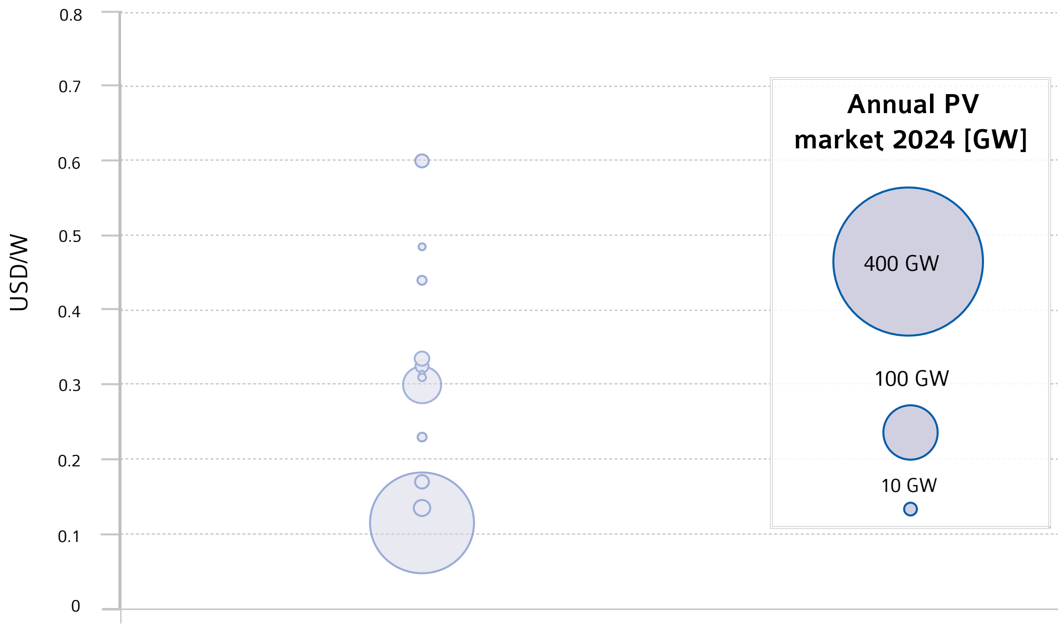
MODULE PRICES / CONTINUED

For lowest achievable prices that have been reported for utility scale systems, the price of PV modules in 2024 (shown in Figure 6.2) accounted for approximately 20% to 35% of the total price. As a direct consequence of the large volumes of manufacturing that came online in 2023, production volumes were well above the market's capacity to absorb in 2023 as well as in 2024. Low as they were already in 2023, prices continued to drop into 2024 and the lowest price of modules in the reporting countries was below 0.10 USD/W.

Looking back to understand past and present price trends, the Chinese decision to strictly limit PV subsidies in May 2018 led to a new imbalance between production and demand, with dozens of GW of new production capacities added in 2017 and 2018 in all segments of the value chain while the global PV market was stagnating. The price decrease that followed accelerated some project development and can be considered at least partially responsible for the market growth in 2020. The year 2021 had seen the rise of multiple raw material prices. In particular, PV polysilicon average spot prices rose significantly during the year, up from around 10 USD/kg in early 2021. Other key raw materials such as PV glass, copper or aluminium maintained their high prices reached at the end of 2020 and the whole PV value chain was subject to increases in transportation costs. Costs and hence prices remained high through 2022, and manufacturers upgraded capacity through this time. By 2023 new manufacturing capacity was coming online as there was a polysilicon price drop that cascaded through to cells and modules, and with a surge in module availability, prices began to drop. By the end of 2023, and despite important efforts in China to stimulate the market enough to absorb the surge in manufacturing capacity, oversupply was impacting the module price for Chinese-made modules. The consequences of the policy decisions in the USA in years previous to the ramping up of manufacturing capacity meant the bulk of Chinese modules - that were not installed domestically - were exported to Europe. By late December 2023, mainstream modules had reached prices that analysts considered under manufacturing cost. Looking in depth at the revenues of some manufacturers among the most competitive, it appears that average sales are above these low prices. It can also be assumed that such prices are obtained with new production lines in which production costs are significantly lower than previously existing ones. In 2024, production volumes continued to increase although not as much as from 2022 to 2023, and the oversupply situation persisted.

Higher module prices are still observed, specifically in the residential segment in countries with historically high prices such as Japan or France.

FIGURE 6.3: INDICATIVE MODULE PRICES IN SELECTED REPORTING COUNTRIES



SOURCE IEA PVPS & OTHERS

SYSTEM PRICES

Reported prices for PV systems vary widely and depend on a variety of factors including system size, location, customer type, connection to an electricity grid, technical specifications, and the extent to which end-user prices reflect the real costs of all the components. For more detailed information, the reader is directed to each country's national survey report on the IEA PVPS website (www.iea-pvps.org).

Figure 6.4 shows the range of system prices in the global PV market in 2024. It shows that around 79% of the PV market consists of prices below 1 USD/W. Large distributed PV systems start at around 0.60 USD/W while utility-scale PV saw prices as low as 0.33 USD/W. BIPV can be seen as a series of segments where the prices can significantly diverge. Off-grid applications suffer from a similar situation, with totally different cases illustrated at different prices. In general, the price range decreased from the previous year for all applications.

On average, system prices for the lowest-priced off-grid applications are significantly higher than for the lowest-priced grid-connected applications. This is mainly attributable to the relatively higher transport costs to access the sites. Indeed, large-scale off-grid systems are often installed in places far from the grid but also far from major towns and highways. Higher prices asked for such installations also depend on higher costs for the transport of components, and technicians, without even mentioning the higher costs of maintenance. In 2024, the lowest system prices in the off-grid sector, irrespective of the type of application, typically ranged from about 1 USD/W to 6 USD/W but prices for some specific applications can be higher. The large range of reported prices in Figure 6.5 is a function of the country and project-specific factors. The highest prices haven't been included in the figures given the very low level of installations: in general, off-grid prices have been averaged in the figures for readability reasons.

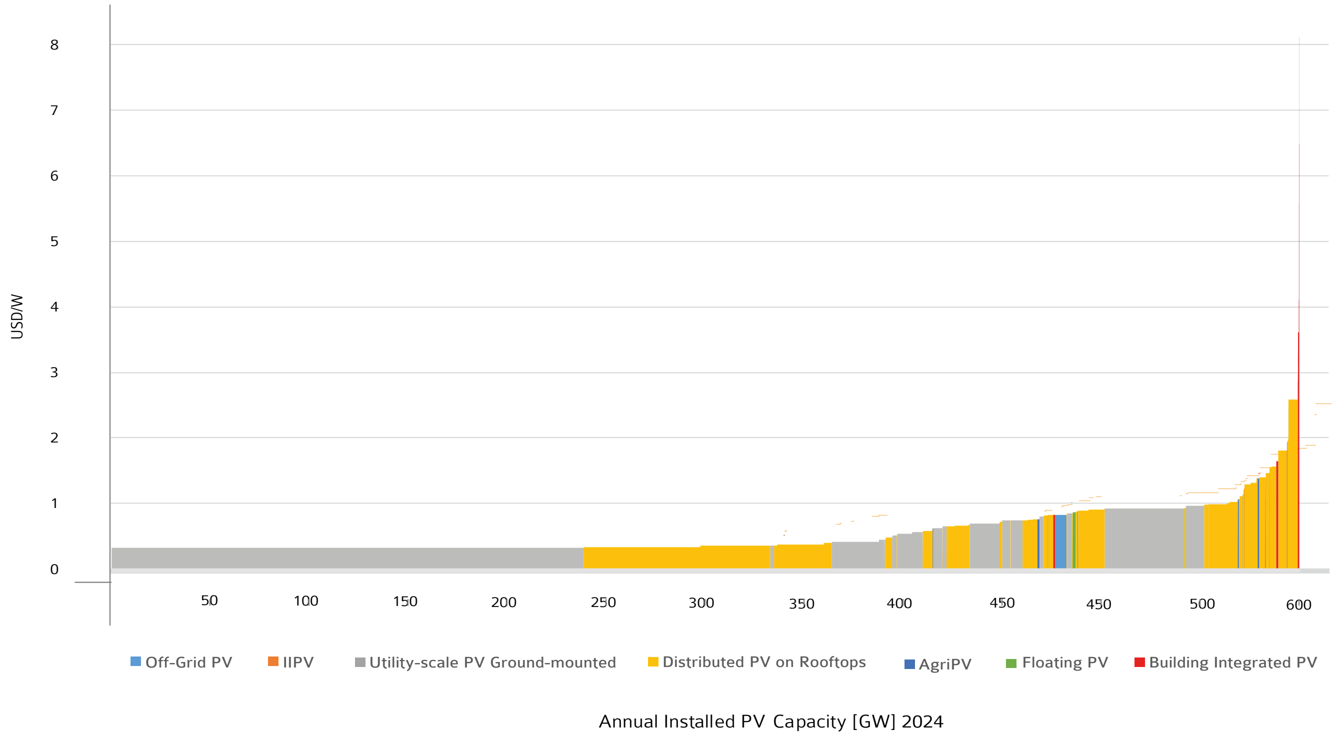
Four specific segments are developing that are likely to grow significantly in volume in countries with limited land. System prices in these segments can vary widely, both from local labour and material costs but also given the inherent constraints specific to the sites used, and as module prices are a smaller proportion of cost, system prices have maintained the wide variety seen in 2023.

- Floating PV – costs vary with anchoring for local weather, salinity, system size and grid connection.
- Linear PV systems along roads, trainline and canals – costs vary depending on size, electrical architecture and grid connection, and can be as low as ground mounted utility sale system but tend to be higher.
- Parking canopies over commercial and industrial car parks – costs vary depending on the type of supports and system size, but are above ground mounted system costs.
- Agrivoltaics either in inter-row grazing or above crops - costs vary from as low as utility scale ground mounted systems when associated with grazing up to BIPV-level costs for specialised mobile systems above crops

More expensive grid-connected system prices are often associated with roof-integrated slates, tiles, building integrated designs or single bespoke projects: BIPV systems in general are considered more expensive when using dedicated components, and the drop in module prices is impacted some, but not all, BIPV products.

SYSTEM PRICES / CONTINUED

FIGURE 6.4: 2024 PV MARKET COSTS RANGES



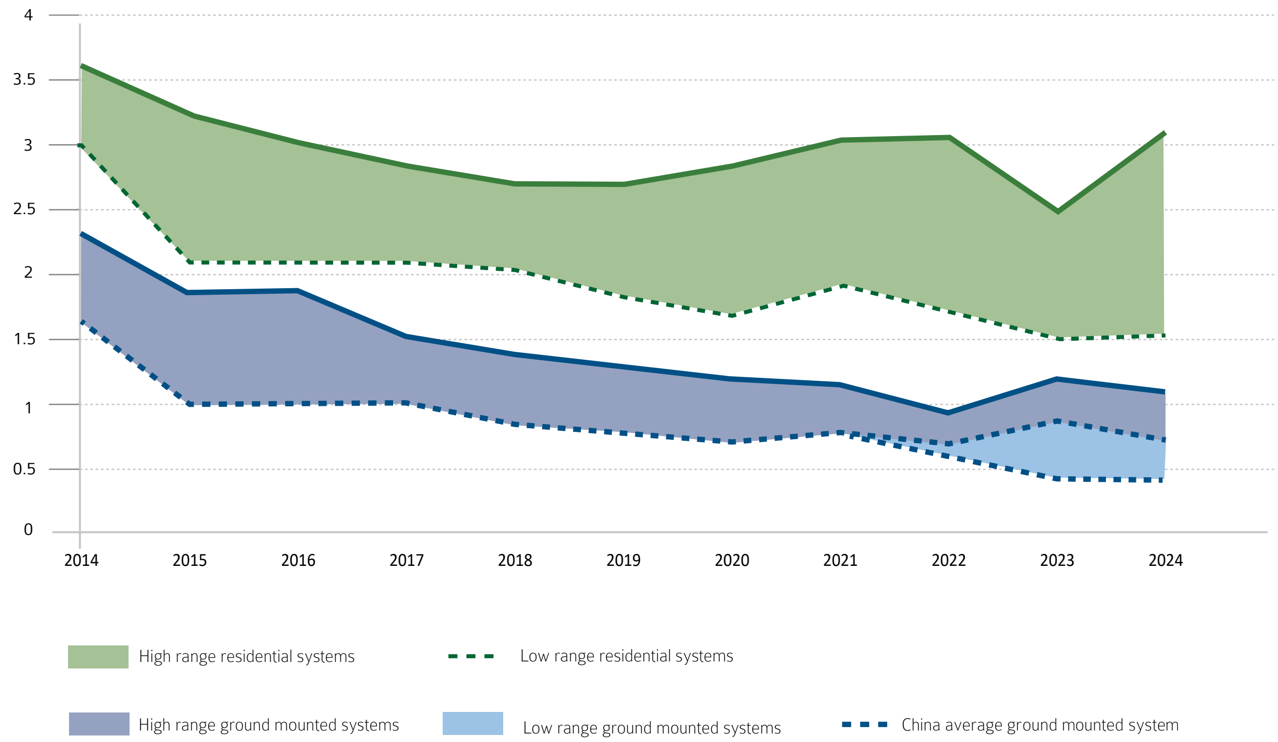
Note: Utility and distributed PV are distributed according to volumes and costs. Floating, Linear, AgriPV and Offgrid PV are indicative average maximum / minimum price points; the real costs are spread between these two points with outliers

SOURCE IEA PVPS & OTHERS

In 2024 residential PV systems price typically ranged from 0.65 USD/W to 3.15 USD/W (with costs in China below this and costs above this in Switzerland) while utility-scale PV systems prices typically ranged from 0.33 USD/W to 1.17 USD/W in 2024 according to the data collected – a similar range as in 2023. These typical price ranges give an overview of the market, but they don't consider the full range of prices practiced across the world – residential systems have, in reality, a much wider range depending on local contexts, with prices below this range depending on labour and administrative costs and the size of systems, and prices going above this range for systems using BIPV products, high end inverters and monitoring or simply scarce labour. Utility scale systems can also go beyond this, particularly on the bottom range, when project developers work aggressively to secure land or for particularly large systems.

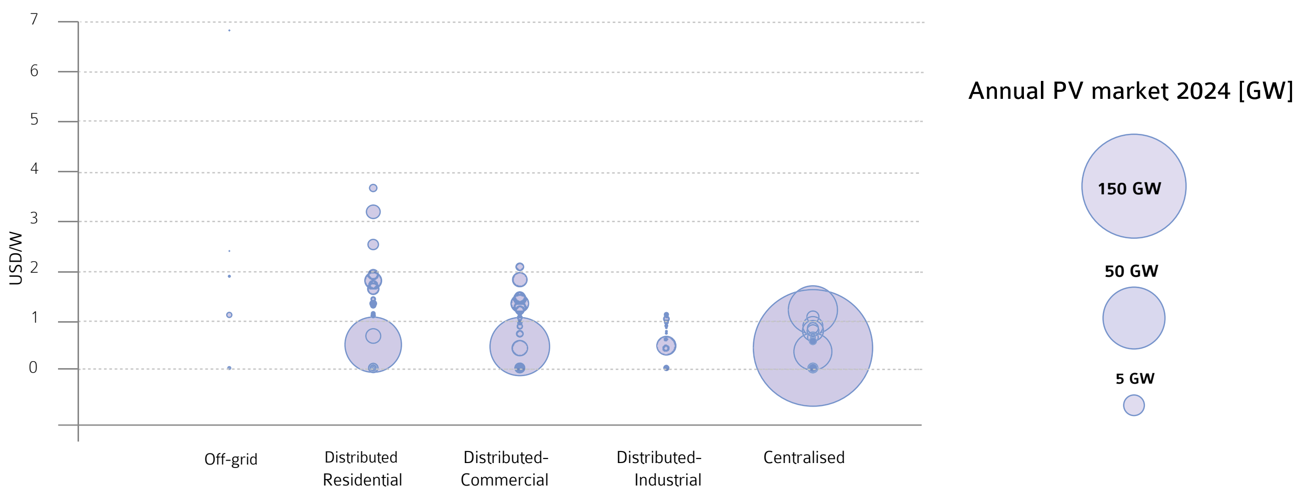
SYSTEM PRICES / CONTINUED

FIGURE 6.5: EVOLUTION OF RESIDENTIAL AND GROUND MOUNTED SYSTEMS PRICE RANGE 2014 - 2024 (USD/W)



SOURCE: IEA PVPS & OTHERS

FIGURE 6.6: INDICATIVE INSTALLED SYSTEM PRICES IN SELECTED IEA PVPS REPORTING COUNTRIES IN 2024



SOURCE: IEA PVPS & OTHERS

SYSTEM PRICES / CONTINUED

The lowest achievable installed price of grid-connected systems in 2024 also varied between countries as shown in Figure 6.6. The average price of these systems is tied to the segment. Large grid-connected installations can have either lower system prices depending on the economies of scale achieved, or higher system prices where the nature of the building integration and installation, degree of innovation, learning costs in project management and the price of custom-made modules may be considered as quite significant factors. In summary, system prices for utility-scale PV mostly remained similar to the ranges observed in 2023. While module prices continue to decrease throughout 2024, soft costs and margins remained stable, and interest rates rose. System prices below 0.5 USD/W for large-scale PV systems were common in very competitive tenders and in China or in India. The question of the lowest CAPEX is not always representative of the lowest LCOE: the case of utility-scale PV with trackers illustrates this, with additional CAPEX translating into a significantly higher LCOE.

Additional information about the systems and prices reported for most countries can be found in the various National Survey Reports.

COST OF PV ELECTRICITY

In order to compete in the electricity sector, PV technologies need to provide electricity at a cost equal to or below the cost of other technologies – unless other criteria are a determining factor. Obviously, power generation technologies are providing electricity at different costs, depending on their nature, the cost of fuel, the cost of maintenance and the number of operating hours during which they are delivering electricity.

The competitiveness of PV can be defined simply as the moment when, in a given situation, PV can produce electricity at a cheaper price than other sources of electricity that could have delivered electricity at the same time. Therefore, the competitiveness of a PV system is linked to the location, the technology, the cost of capital, and the cost of the PV system itself, which highly depends on the nature of the installation and its size. However, it will also depend on the environment in which the system will operate. Off-grid applications in competition with diesel-based generation will not be competitive at the same moment as a large utility-scale PV installation competing with the wholesale prices on electricity markets. In sum, the competitiveness of PV is connected to the type of PV system and its environment.

GRID PARITY

Grid Parity (or Socket Parity) refers to the moment when PV can produce electricity (the Levelized Cost of Electricity or LCOE) at a price below the price of electricity bought from the grid. While this is valid for pure players (the so-called "grid price" refers to the price of electricity on the market), this is based on two assumptions for prosumers (producers who are also consumers of electricity):

- That PV electricity can be consumed locally (either in real-time or through some compensation scheme such as local or delocalized net metering);
- That all the components of the retail price of electricity can be compensated when it has been produced by PV and locally consumed.

Technical solutions can be used to increases the self-consumption level (demand-side management including EV charging or direct use to heat water with heat pumps, local electricity storage, reduction of the PV system size, delocalized self-consumption, energy communities, etc.).

If only a part of the electricity produced can be self-consumed, even after actioning levers for increased self-consumption, as mentioned above, then the remaining part must be injected into the grid and should generate revenues of the same order as, at least, any centralized production of electricity. Today this is often guaranteed for small size installations by the possibility of receiving a FiT (or similar) for the injected electricity through net billing schemes. However, when grids are under strain, when local or regional generation exceeds demand, it is possible that excess electricity either cannot be injected into the grid (i.e. must be curtailed) or will not be financially compensated – as may soon be the case in parts of Australia, Austria, USA, amongst other countries experiencing grid constraints in the residential and commercial sectors.

The price paid for electricity by consumers is composed in general of four main components:

- The procurement price of electricity, on electricity markets plus the margins of the reseller;
- Grid costs and fees, partially linked to the consumption, partially fixed; the key challenge is their future evolution;
- Taxes;
- Levies (used among other things to finance the incentives for some renewable sources, social programmes, solidarity between regions etc.);

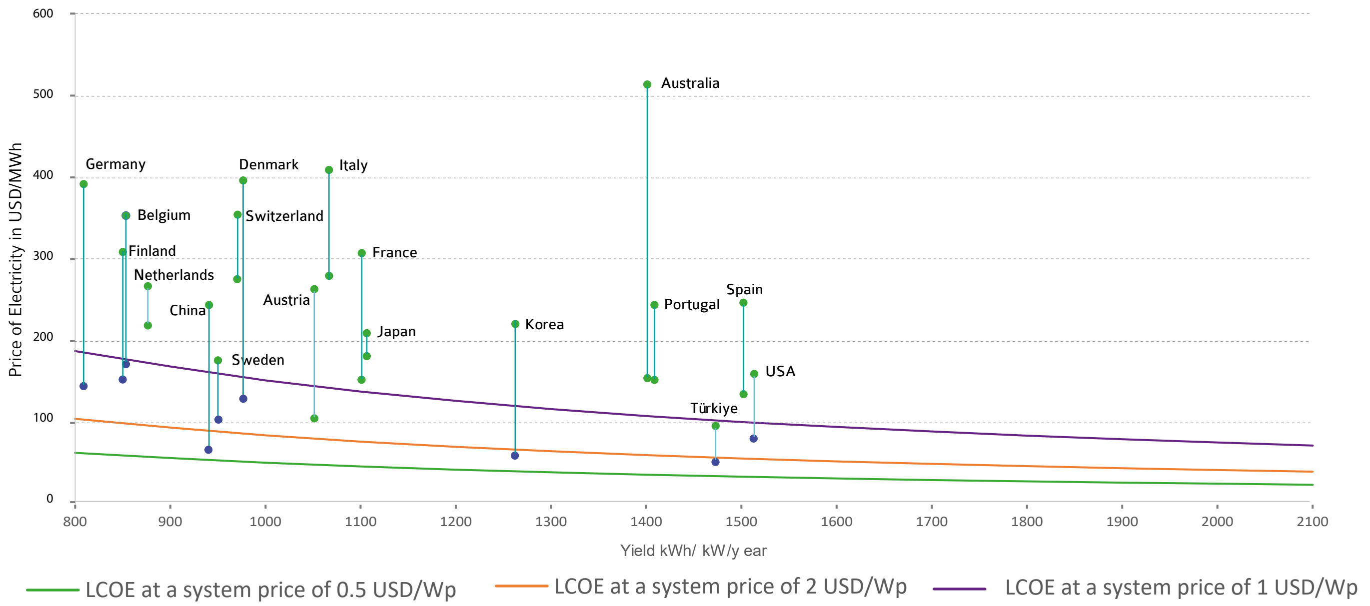
If the electricity procurement price can be compensated, the two other components require considering the system impact of such

COST OF PV ELECTRICITY / CONTINUED

measures: with tax loss on one side and the lack of financing of distribution and transmission grids on the other. While the debate on taxes can be simple, since PV installations are generating taxes as well, the one on grid financing is more complex. Even if self-consumed electricity could be fully compensated, alternative ways to finance the grid should be considered given the loss of revenues for grid operators - or a better understanding of PV positive impacts on the grid should be achieved.

Any support or compensation measures for the excess electricity after self-consumption should take into account these last elements and the question of equitable and ethical sharing of the cost burden for grids and supports schemes should become an increasingly important subject as PV penetration rates increase.

FIGURE 6.7: LCOE OF PV ELECTRICITY AS A FUNCTION OF SOLAR IRRADIANCE & RETAIL PRICES IN KEY MARKETS*



*NOTE: THE COUNTRY YIELD (SOLAR IRRDIANCE) HERE SHOWN MUST BE CONSIDERED AS AN AVERAGE

SOURCE IEA PVPS & OTHERS

THE LOWEST ELECTRICITY PRICES (RESPECTIVELY THE HIGHEST) DISPLAYED PER COUNTRY SHOULD BE SEEN AS AN AVERAGE VALUE FOR INDUSTRIAL CONSUMERS (RESPECTIVELY RESIDENTIAL CONSUMERS).

Figure 6.7 shows the range of retail prices in selected countries based on their average solar resource and the indicative PV electricity threshold for three different system prices (0.5, 1 and 2 USD/W, converted into LCOE). Green dots are cases where PV is competitive in most of the cases. Blue dots show where it really depends on the system prices and the retail prices of electricity.

The figure demonstrates how grid parity had been reached for almost all IEA PVPS countries as a result of rising electricity costs and dropping PV costs. In this figure, the lower range of electricity prices is, with the exception of France, for commercial and industrial consumer, whilst the higher is for residential customers. In 2022, retail and commercial/industrial electricity prices rose quite steeply in most countries, increasing the competitiveness of PV – and whilst in many countries, particularly in the EU, commercial electricity prices dropped slowly through 2023 and again in 2024, the drop in module prices means that competitiveness is here to stay.

In some specific segments, determining the competitiveness of a PV system is not just dependent on the system or electricity costs, but also on other avoided costs, as for BIPV, for example. The specific case of BIPV consists, for new or renovated roofs, to assess the competitiveness for the BIPV solution minus the costs of the traditional roofing (or façade) elements. The rest of the assessment is similar to any building under self-consumption using a standard BAPV solution. Of course, if the BIPV solution has to be installed on a building outside of any planned works, this doesn't

COST OF ELECTRICITY / CONTINUED

apply. Metrics used for buildings can also be different, since the integration of PV components might be justified by non-economic factors or the perspective of an added value. For such reasons, BIPV competitiveness is in general assessed against the traditional building costs.

COMPETITIVENESS OF PV ELECTRICITY WITH WHOLESALE ELECTRICITY PRICES

In countries with an electricity market, wholesale electricity prices when PV produces are one benchmark of PV competitiveness. These prices depend on the market organisation and the technology mix used to generate electricity. In order to be competitive with these prices, PV electricity has to be generated at the lowest possible price. This is already achieved with large utility-scale PV installations that allow reaching the lowest system prices today especially when they come with low maintenance costs and a low cost of capital. An increasing number of countries have had utility scale systems commissioned that sell directly on the market – including Croatia, Italy, Germany, Norway, Sweden, Portugal, Romania, Philippines, Spain, Australia and the USA; indeed, in these last three countries it is increasingly becoming a common option.

Energy-only markets are also likely to be soon completemented by grid services that could add additional revenues.

These types of business models, exposed to the market, remain riskier than conventional ones that guarantee prices paid to the producer over 15 years or more. The key risk associated with such business models lies in the evolution of wholesale market prices on the long term and the potential effects of what is known as price cannibalisation: large volumes of PV generated electricity reduce market prices during the midday peak when penetration becomes significant. However, with high penetration rates and the shift to electricity for transport and heating, it is unclear if price cannibalisation will be a real issue or not in the long term. prices during PV production peaks will drop and impair the ability to remunerate investments, or low prices will attract additional electricity demand and will stabilise the market prices. At this point, both options remain possible. When a wholesale market doesn't exist as such, (in China for instance), the comparison point is the production cost of electricity from coal-fired power plants.

FUEL-PARITY AND OFF-GRID SYSTEMS

Off-grid systems including hybrid PV/diesel can be considered competitive when PV can provide electricity at a cheaper cost than the conventional generator. For some off-grid applications, the cost of the battery bank and the charge controller should be considered in the upfront and maintenance costs while a hybrid system will consider the cost of fuel saved by the PV system.

The point at which PV competitiveness will be reached for these hybrid systems takes into account fuel savings due to the reduction of operating hours of the generator. Fuel-parity refers to the moment in time when the installation of a PV system can be financed with fuel savings only. It is assumed that PV has reached fuel-parity, based on fuel prices, in numerous Sunbelt countries.

Other off-grid systems are often not replacing existing generation sources but providing electricity in places with no network and no or little use of diesel generators. They represent a completely new way to provide electricity to hundreds of millions of people all over the world.

PRODUCING COMPETITIVE GREEN HYDROGEN AND OTHER MOLECULES WITH PV

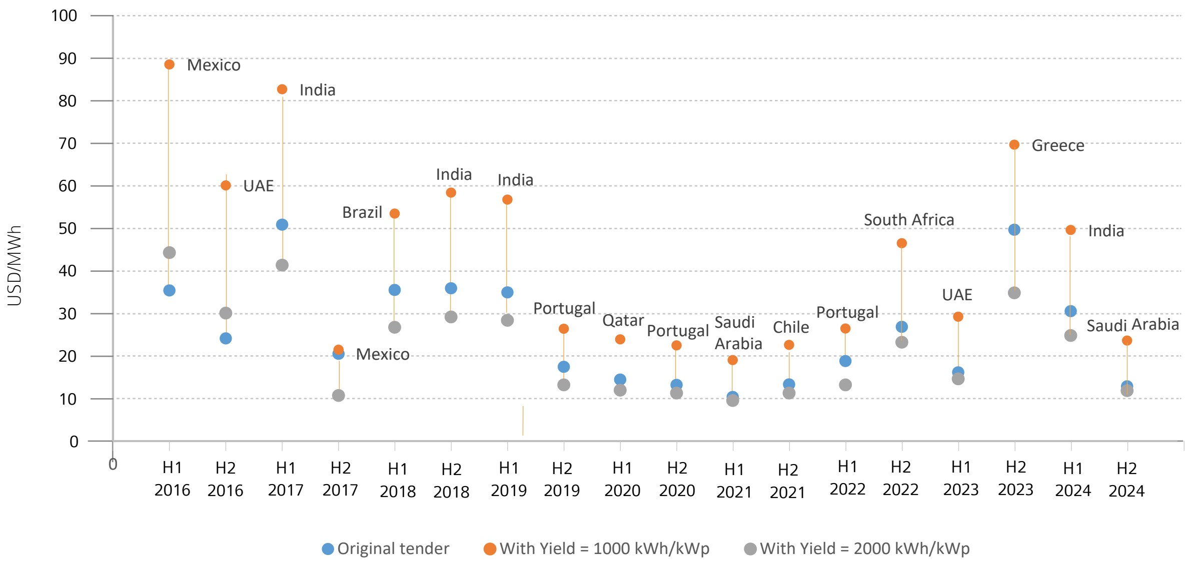
The declining cost of PV electricity opens the door for other applications such as green hydrogen and/or ammonia directly from PV (possibly in combination with wind). The cost of electrolysers is also decreasing as commissioned volumes of electrolysers increases; however, despite the increased gas prices after the war in Ukraine, competitiveness with "black" hydrogen is still only on the horizon and is not yet a reality. Different uses for hydrogen - industrial applications, transport, agriculture (through ammonia) - are expected to create a tremendous opportunity for PV to produce hydrogen without being connected to the grid.

Large projects have been announced around the world with several commissioned already including two systems in China with 150 MW / 300 MW of PV and a smaller project in Japan. The business model is being explored in a wide range of countries, with increasingly large multi-GW scale projects in preliminary phases across Australia, the USA, Brazil and Africa (Mauritania) and the Middle East (Oman, Egypt) - countries where high irradiance and low land costs are expected to allow for competitive conditions.

COST OF PV ELECTRICITY / CONTINUED

LOW TENDERS PRICES

FIGURE 6.8: NORMALISED LCOE FOR SOLAR PV BASED ON LOWEST PPA PRICES 2016 - Q4 2024



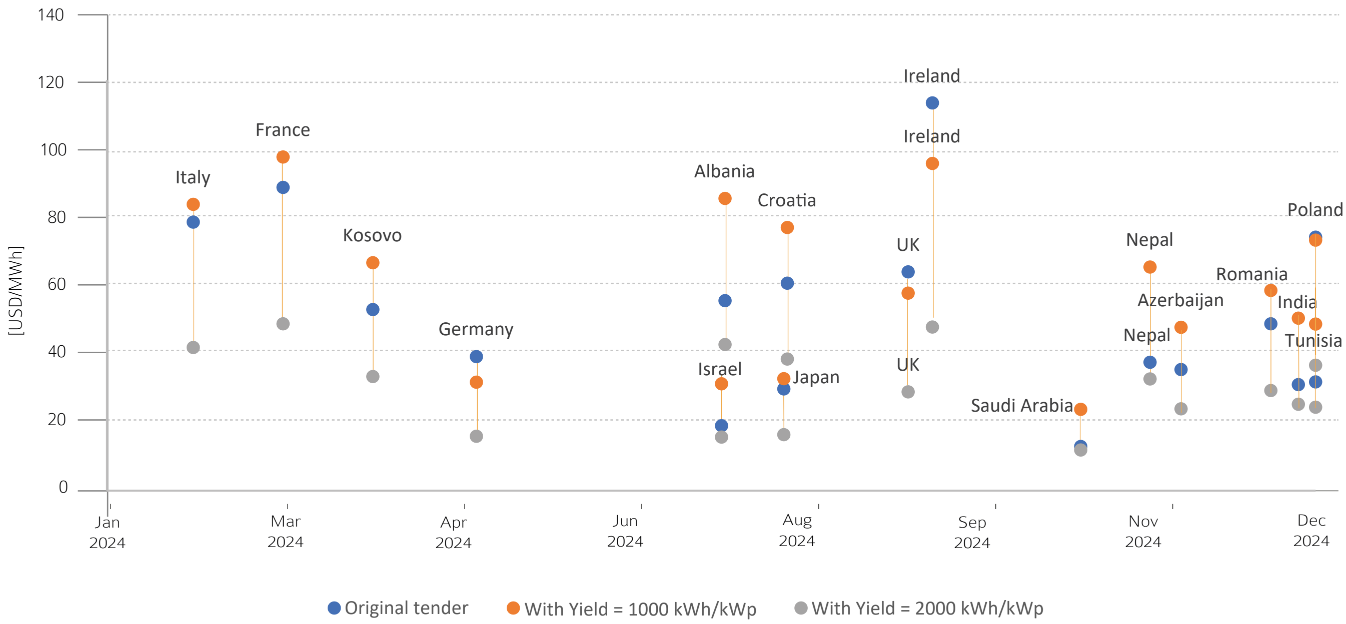
SOURCE IEA PVPS & OTHERS

With several countries having adopted tenders as a way to allocate PPAs to PV projects, the value of these PPAs achieved record low levels in 2020 and some low prices in 2021 as well. In 2022 and 2023, because of the higher electricity market prices (Europe, USA, Australia) PPA's were negotiated at higher prices too. In 2024, PPA prices followed a downward trend, with several agreements falling below 40 USD/MWh, including one in Saudi Arabia at 12.9 USD/MWh, ranking among the ten lowest prices ever recorded. The high level of certainty when it comes to solar generation levels and operating costs has become attractive on markets where many industrial and commercial consumers were significantly impacted by the volatile electricity market prices of late 2022 and early 2023. It is increasingly worth paying a slight premium for the price stability. In parallel, solar is an increasingly attractive option for companies investing in renewable energy for renewable energy targets and corporate social responsibility goals such as the RE100 initiative.

Solar PPA prices seen in 2024 ranged from about 12.9 USD/ MWh to 113 USD/MWh - a wider range than in 2023, with a clear difference in regional evolution. Europe reported the highest prices in 2024, among which we find Ireland with 113 USD/MWh, France 89 USD/ MWh and Italy 78 USD/MWh, although Germany reported a PPA values below 40 USD/MWh. In contrast, Middle East and Africa reported the lowest PPA prices, led by Saudi Arabia second all time lowest of 12.9 USD/MWh and followed by Israel's 18.9 USD/MWh. Whilst in the past most solar PPA's were for new and to be developed systems, in the coming years they will be for existing capacity reaching the end of current contracts under support mechanisms or initial PPA's.

COST OF PV ELECTRICITY / CONTINUED

FIGURE 6.9: NORMALISED LCOE FOR SOLAR PV BASED ON RECENT PPA PRICES 2024



SOURCE: IEA PVPS & OTHERS

TABLE 6.1: TOP 10 LOWEST WINNING BIDS IN PV TENDERS FOR UTILTY SCALE PV SYSTEM

REGION	COUNTRY/STATE	USD/MWH	YEAR
MIDDLE EAST AND AFRICA	SAUDI ARABIA	10.4	2021
MIDDLE EAST AND AFRICA	SAUDI ARABIA	12.9	2024
EUROPE	PORTUGAL	13.2	2020
THE AMERICAS	CHILE	13.3	2021
MIDDLE EAST AND AFRICA	UAE	13.5	2020
ROW	QATAR	14.5	2020
EUROPE	SPAIN	15.0	2021
EUROPE	PORTUGAL	16.0	2019
MIDDLE EAST AND AFRICA	UAE	16.2	2023
THE AMERICAS	BRAZIL	17.5	2019

SOURCE: IEA PVPS & OTHERS

TABLE 6.2: LOWEST WINNING BIDS IN PV TENDERS FOR UTILTY SCALE PV SYSTEM PER REGION

REGION	COUNTRY/STATE	USD/MWH	YEAR
ASIA	UZBEKISTAN	17.9	2021
AFRICA	TUNISIA	24.4	2019
EUROPE	PORTUGAL	13.2	2020
LATIN AMERICA	CHILE	13.3	2021
NORTH AMERICA	MEXICO	20.6	2017
MIDDLE EAST	SAUDI ARABIA	10.4	2021

SOURCE: IEA PVPS & OTHERS

seven

PV IN THE ENERGY SECTOR

PV ELECTRICITY PRODUCTION

TRACKING OF PV INSTALLED CAPACITY

Tracking PV installations in all the regions of the world can be challenging as many countries do not accurately keep track of the PV systems installed or do not make the data publicly available. Data published by IEA PVPS reports on new annual installed capacity and total cumulative installed capacity and is based on official data in reporting countries. For the purposes of this report, when individual countries do not publish any reporting data, estimated volumes have been made based on trade data (import volumes), and adjusted to take into account the delays between importing volumes and installation and commissioning.

Depending on reporting practices, cumulative capacity (the sum of new annual capacity) may outstrip operating capacity as systems are decommissioned. Repowered capacities not only replace some decommissioned capacity but also generally increase operational capacity, as the repowered capacity is higher than the initial plant capacity due to PV module efficiency improvements.

There is no standardised reporting on these subjects across IEA PVPS countries. Several countries already incorporate decommissioning of PV plants in their total capacity numbers by reducing the total cumulative number. Other countries report capacity in operation for that year, and do not include repowered volumes in new annual capacity or decommissioned volumes in operational capacity. Many countries do not track decommissioning or repowering with any consistency.

Repowering is still relatively unusual given the age of the oldest installations, but it is increasing - serial defects with backsheets manufactured in the period 2009 – 2011 is a good example, as several hundred MW were replaced over a short few years. Module capacity that has been used to repower systems with defective or underperforming modules will appear in shipped volumes but not necessarily in new annual installations. Real decommissioning is expected to be rare, as land usage constraints and cheaper PV on buildings encourages repowering. Recycling numbers can provide a glimpse of what is happening with regards to repowering and decommissioning in countries where recycling schemes are active, however recycling volumes are underestimating decommissioning due to an active (and sometimes barely legal) second-hand market, especially towards Africa; also, reporting is often in tonnage and the availability of data must be improved before it can be used more generally.

IEA PVPS is following the dynamic evolution of decommissioning, repowering and recycling closely, however giving numbered estimates is not possible yet, so the expected impact on the installed capacity, market projections for repowering and the decline in PV performances due to ageing PV systems is not quantified.

ESTIMATING PV PRODUCTION

Estimating PV electricity production is easy to measure at a power plant but much more complicated to compile for an entire country. Not only the installed capacity must be accurately tracked, which requires an effective and consistent approach (especially for distributed, self-consumption and off-grid segments), but also, electricity production is impossible to accurately estimate from installed PV capacity for a given year, because estimations are based on the installed capacity without knowledge of when, during the year, that capacity was installed. A system installed at the end

PV ELECTRICITY PRODUCTION / CONTINUED

of the year will have produced only a small fraction of its theoretical annual electricity output.

Additionally, estimates are based on a theoretical annual production, and do not take into account different performance levels based on azimuth and inclination or even other factors such as system ventilation or shading., A system installed west facing will generate less over the year than one installed facing the equator. Performance losses due to aging of PV plants are not considered at this point. Some plants may have experienced production issues, due to technical problems or external constraints.

For these reasons, the electricity production from PV per country in this report is an estimate of what the minimal theoretical production should be the following year, when all the PV systems installed at the end of the year have generated electricity for one year.

To calculate this "next year's minimal theoretical PV production", an average solar yield in the country is used. Depending on the country, this value is either provided through National Survey Reports and is calculated as the total solar generation divided by total solar capacity, or is a representative value taken from geographical irradiance atlases – these yields are an approximation of the reality.

Nationally produced statistics on solar generation will in general reflect real production injected into the grid – consequently, in years with high new capacity additions, the theoretical value used here can be well above official statistics for the current year – and well below that of the next year. The real PV production in a country is increasingly difficult to assess even if tracked by transmission system operators (TSO's), as more and more volumes of generation are self-consumed (i.e. not metered) and storage enters into consideration, increasing self-consumption levels or curtailing generation to fit storage. IEA PVPS advocates for governments and energy stakeholders, including grid operators to create accurate databases and precisely measure PV production.

PV PENETRATION

PV electricity penetration can be two different indicators – either the installed capacity per capita, as seen in Chapter 2; or, as used here, the share of electricity consumption supplied by PV generation. Here it is the ratio between PV electricity production in a country and the electricity demand in that country and is expressed as a percentage. It is based on the theoretical electricity production from PV per country, calculated as indicated in the section above. Electricity demand is obtained via publicly available databases and via the IEA PVPS experts; when possible, it has been adjusted to consider self-consumption volumes.

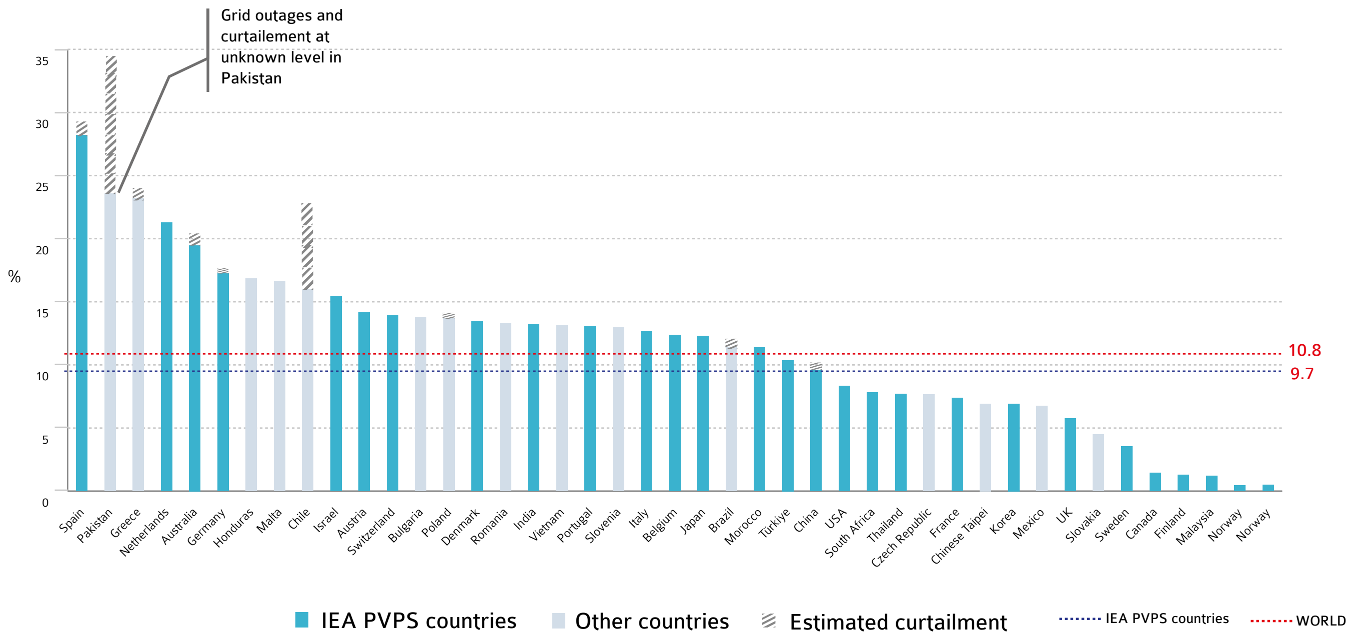
The PV penetration rates here are an estimate and are likely to differ from official PV production and penetration numbers in many countries for the reasons detailed above - they should be considered as indicative, providing a reliable estimation for comparison between countries and do not replace official data.

To illustrate this divergence, the national TSO reported on production data in France, and gave the PV penetration at 5.7% for 2024, just below last year's IEA PVPS estimation of 5.8% but well below estimations for this report at 7.0%. In Spain the TSO reported it as 17% for 2024, well below our estimated 19.7% last year and 28% this year. The difference from Spain is due to the fact that the TSO does not take into consideration the large volume of distributed PV in Spain – consequently, the divergence is expected.

Of the 35 IEA PVPS and non-IEA PVPS countries studied, all but one (Norway) produced at least 1% of their electricity demand from PV in 2024 – and more than half (21) should be producing more than 10% next year.

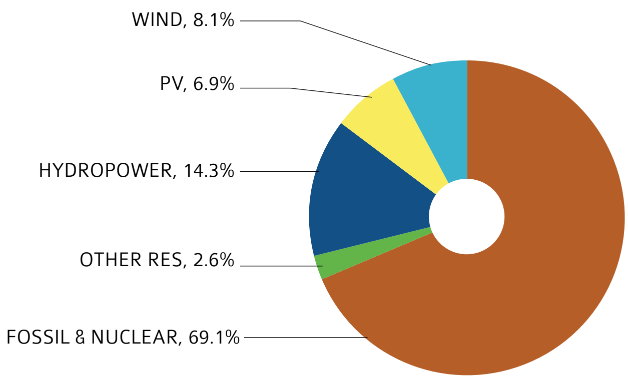
Concerning global PV penetration, with around 2 261 GW installed worldwide, PV could produce almost 2 939 TWh (see Table 7.1) of electricity on a yearly basis if an average yield of 1300kWh/kWp is considered. This represents around 10.8% of the global electricity demand covered by PV, up on 2023 – with a wide range of differing contributions from one country to another, as demonstrated in Figure 7.1.

FIGURE 7.1: PV CONTRIBUTION TO ELECTRICITY DEMAND 2024



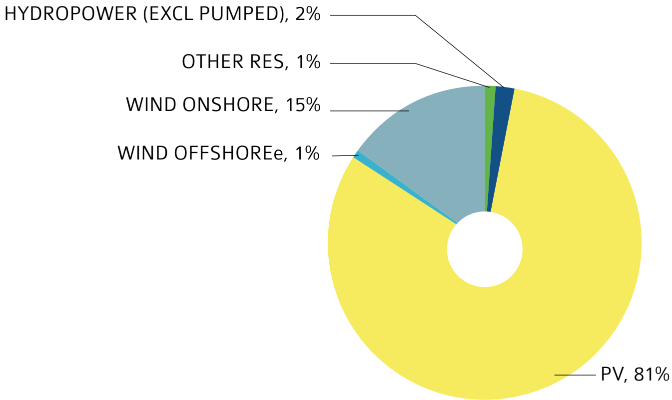
SOURCE IEA PVPS & OTHERS

FIGURE 7.2: SHARE OF RENEWABLE IN THE GLOBAL ELECTRICITY PRODUCTION IN 2024



SOURCE REN21, IEA PVPS

FIGURE 7.3: NEW RENEWABLE INSTALLED CAPACITY IN 2024



SOURCE REN21, "GWEC, IHA, IEA PVPS

PV ELECTRICITY PRODUCTION / CONTINUED

TABLE 7.1: 2024 PV ELECTRICITY STATISTICS IN IEA PVPS COUNTRIES

COUNTRY	FINAL ELECTRICITY CONSUMPTION	HABITANTS	GDP 2024	SURFACE	AVERAGE YIELD	PV ANNUAL INSTALLED CAPACITY 2024	PV CUMULATIVE INSTALLED CAPACITY 2024	PV ELECTRICITY PRODUCTION	ANNUAL CAPACITY PER HABITANT	CUMULATIVE CAPACITY PER HABITANT	CUMULATIVE CAPACITY PER KM²	THEORETICAL PV PENETRATION
	Twh	Million	BUSD	km²	kWh/kWp	WMW	MW	TWh	W/Hab	W/Hab	kW/km²	%
AUSTRALIA	273.3	27.2	1 752.2	7 690 000	1 400	5 289	39 810	55.7	194.4	1 463.4	5.2	20.4%
AUSTRIA	66.0	9.2	521.6	83 883	1 050	2 509	8 903	9.3	273.4	970.0	106.1	14.2%
BELGIUM	80.5	11.9	664.6	30 688	853	978	11 663	9.9	82.3	982.0	380.1	12.4%
CANADA	564.0	41.3	2 241.3	9 985 000	1 150	321	7 597	8.7	7.8	184.0	0.8	1.5%
CHINA	9 852.1	1 409.0	18 743.8	9 634 000	940	357 265	1 048 508	985.6	253.6	744.2	108.8	10.0%
DENMARK	38.4	6.0	429.5	44 000	975	708	5 293	5.2	118.4	885.6	120.3	13.4%
FINLAND	83.0	5.6	299.8	338 432	850	245	1 249	1.1	43.5	221.5	3.7	1.3%
FRANCE	442.2	68.5	3 162.1	551 500	1 100	6 010	29 679	32.6	87.7	433.2	53.8	7.4%
GERMANY	463.0	83.5	4 659.9	357 588	808	17 220	100 424	81.1	206.2	1 202.5	280.8	17.5%
INDIA	1 532.0	1 450.9	3 912.7	357 172	1 625	31 910	124 555	202.5	22.0	85.8	348.7	13.2%
ISRAEL	70.0	10.0	540.4	20 770	1 650	900	6 558	10.8	90.2	657.5	315.7	15.5%
ITALY	312.3	59.0	2 372.8	302 070	1 066	6 682	37 020	39.5	113.3	627.6	122.6	12.6%
JAPAN	869.0	124.0	4 026.2	377 975	1 100	5 620	97 037	106.7	45.3	782.7	256.7	12.3%
KOREA	558.0	51.8	1 712.8	100 401	1 261	2 500	30 658	38.7	48.3	592.4	305.4	6.9%
MALAYSIA	776.0	35.6	422.0	330 621	1 314	978	7 191	9.4	27.5	202.2	21.7	1.2%
MOROCCO	37.6	38.1	154.4	710 850	1 750	728	2 442	4.3	19.1	64.1	3.4	11.4%
NETHERLANDS	110.0	18.0	1 227.5	41 500	875	3 400	26 737	23.4	188.9	1 485.9	644.3	21.3%
NORWAY	138.7	5.6	483.7	323 806	760	166	822	0.6	29.8	147.5	2.5	0.5%
PORTUGAL	57.7	10.7	308.7	92 225	1 407	1 476	5 369	7.6	137.9	501.7	58.2	13.1%
SOUTH AFRICA	194.0	64.0	400.3	1 219 090	1 733	1 235	8 738	15.1	19.3	136.5	7.2	7.8%
SPAIN	247.0	48.8	1 722.7	505 990	1 500	8 665	47 616	71.4	177.5	975.6	94.1	28.9%
SWEDEN	W135.9	10.6	610.1	410 000	950	934	5 073	4.8	88.4	480.0	12.4	3.5%
SWITZERLAND	57.0	9.0	936.6	41 285	970	1 798	8 172	7.9	199.0	904.6	197.9	13.9%
THAILAND	235.0	71.7	526.4	1 219 092	1 522	3 000	11 875	18.1	41.9	165.7	9.7	7.7%
TÜRKIYE	305.0	85.5	1 323.3	783 560	1 471	4 149	21 502	31.6	48.5	251.4	27.4	10.4%
UK	280.0	69.2	3 643.8	1 054 000	902	1 906	17 889	16.1	27.5	258.4	17.0	5.8%
USA	4 082.2	340.1	29 184.9	9 147 282	1 512	47 077	225 015	340.2	138.4	661.6	24.6	8.3%
IEA PVPS	**21 859.9**	**4 164.6**	**85 984.0**	**48 936 251**	**1 300**	**513 669**	**1 937 395**	**2 138.2**	**123.3**	**465.2**	**39.6**	**10%**
BRAZIL	645.0	212.0	2 179.4	30 530	1 506	14 320	52 137	78.5	67.5	245.9	1 707.7	12%
PAKISTAN	110.8	251.3	373.1	907 464	1 708	17 970	22 430	38.3	71.5	89.3	24.7	35%
NON IEA PVPS	**5 307.1**	**3 977.4**	**25 342.3**	**85 389 184**	**1 300**	**87 458**	**323 524**	**801.0**	**22.0**	**81.3**	**3.8**	**15%**
WORLD	**27 167.0**	**8 142.1**	**111 326.4**	**134 325 435**	**1 300**	**601 127**	**2 260 919**	**2 939.2**	**73.8**	**277.7**	**16.8**	**11%**

SOURCE: IEA PVPS 8 OTHERS

Renewable energies contributed nearly 32% to global electricity production in 2024, up 1.7% on 2023. Whilst more than 80% of new capacity was solar, with a lower capacity factor than wind or hydro power, its actual share in annual electricity generation is 6.9% - not to be confused with its share in electricity consumption as demonstrated in Figure 7.1; this is significantly higher as losses across electricity systems are not included.

PV INTEGRATION AND SECTOR COUPLING

THE ENERGY STORAGE MARKET

Energy storage can take different forms – when coupled with PV, this can be batteries in residential standalone and grid tied systems, community sized batteries used to keep microgrids stable where they provide both services and energy, and grid-scale batteries ("big batteries") deployed to provide system services and profit from energy peak management.

In general, distributed battery storage is seen as an opportunity to either solve grid integration issues linked to PV or to increase the self-consumption ratio of distributed PV plants to improve the payback time of PV systems. Storage is an increasingly viable component of grid connected PV systems across the world – from the USA and Australia where it is used to improve pay back times all the way to Pakistan where it allows continued supply in periods of grid outages. The adoption of batteries is on the rise in commercial and industrial segments as companies look to managing energy costs in volatile or costly electricity markets.

In some countries distributed grid tied batteries are encouraged to relieve grid congestion or peak loads, either through subsidies (Australia, Austria, China, Spain, Japan, USA) or the terms attached to self-consumption policies such as time-of-use net billing and/or regulations on new building construction (both notably in use in California in the USA).

Grid-scale batteries are regularly co-located with utility scale PV plants and can be used to stabilize grid injection, reduce curtailment or increase margins by peak shifting generation, provide ancillary services to the grid such as fast response voltage stability or peak power surges. New requirements for grid integration in tenders tend to favour the use of stationary batteries in utility-scale plants to smooth the output of the plant, reduce curtailment or reduce the need for grid capacity reinforcement.

Independently of PV systems, utility scale batteries are being installed around the world and their system size is increasing each year. As discussed in Chapter 3, with positive policy support or favourable market conditions the largest markets for utility scale batteries were China (37 GW new storage in 2024, of which 62% was standalone utility scale batteries), USA, Europe (UK, Italy), Australia (7.8 GW of utility scale storage were under construction in 2024) but also Japan and Korea. In most of the markets, Battery project developers are also developers of solar projects or energy majors. These grid-scale batteries provide services that would otherwise have been provided by turbine-based generation (coal, gas or hydro power), enabling higher PV penetration rates and a faster energy transition.

Globally, the largest part of batteries sold are used for transportation in EVs although stationary storage is growing much faster. The rapid development of electric mobility is driving battery prices down (car batteries dropped below 100 USD/kWh) and manufacturing plant plans could lead to a tripling of capacity in the next years – similarly to the PV industry, standardisation and globalisation of battery technologies and supply chains are likely to have a similar disruptive impact on the energy transition as the explosion of PV manufacturing capacity in the past few years.

THE ELECTRIFICATION OF TRANSPORT

Charging EVs during peak load implies rethinking power generation, grid management and smart metering, and concepts such as virtual self-consumption could provide a framework for EVs as mobile storage for excess PV generation. Vehicle-to-Grid (V2G) and other bidirectional charging applications are being looked at for the ability to support demand response and grid stability. Meanwhile, the use of transport infrastructure such as carports, parking canopies and noise barriers is being explored as a way to supply electricity directly to vehicles or transport networks.

The electrification of transport continues to advance around the world in parallel to the growth of solar, with 20% of new cars being

From PV to VIPV and VAPV With its distributed nature, PV fits perfectly with EV charging during the day when cars are stationed in commercial and office parking or at home. Such slow charging is also highly compatible with distribution grid constraints. Finally, the integration of PV in the vehicles themselves (VIPV), also offers opportunities to alleviate the burden on the grid, increase the autonomy of EVs, provide greater driver comfort and connects the automotive and PV sectors. The IEA PVPS Task 17 deals with this fast-emerging subject.

PV INTEGRATION AND SECTOR COUPLING / CONTINUED

electric in 2024, and China selling more electric cars domestically in 2024 than the whole world just 2 years ago.

THE ELECTRIFICATION OF HEATING AND COOLING

With the development of self-consumption, grid congestion and the need for peak shaving to relieve grid instability, the use of PV led heating and cooling is becoming increasingly common.

Heating with PV is mainly used to heat domestic hot water, as a way of increasing self-consumption, whether it be in response to electricity consumption costs or grid capacity and congestion problems. Domestic hot water manufacturers now integrate devices to directly link extra PV production to the electric boiler.

In hot climates such as Australia, China, Japan, as well as the states of Florida and California (USA), PV has already been used to provide electricity for cooling for several years. In some countries with fragile grids, high electricity costs and hot climates, security of electricity supply for cooling has become a fundamental driver of residential PV, for example in Pakistan where owners of detached dwellings are increasingly investing in PV to ensure air condition loads. As climate change intensifies and electricity costs go up whilst grid infrastructure becomes more fragile to heatwaves, it is likely to drive PV sales in other countries across Asia, central Asia and continental Europe. Commercial companies that intensively use cooling (especially in the food chain), and supermarkets are increasingly turning to PV installations on their buildings to reduce the electricity load of refrigerating units.

The use of solar energy (PV or thermal) for cooling is the subject of the IEA SHC Task 65 (https://task65.iea-shc.org/) that concluded in June 2024, which focused on innovative ways to adapt and develop existing technologies (solar and heat pumps) for sunny and hot climates.

GREEN HYDROGEN AND HYDROGEN DERIVATIVES

Green hydrogen refers to hydrogen produced from renewable sources, as opposed to hydrogen produced from fossil fuels or nuclear power. Hydrogen (or its derivates such as ammonia) is considered essential in hard-to-electrify sectors and bridge seasonal gaps in RES supply. Industrialization projects around the creation of green hydrogen have gained momentum and continue to be funded each year. Hydrogen, or its derivatives, produced by competitive PV can also be stored and used to produce electricity later, even if the overall efficiency decreases significantly. It is seen as a way of increasing PV capacity to supply electricity grids when there is a need, but also to store excess production when grid needs are lower. Systems combining hydrogen with battery storage are being explored for greater flexibility, while module electrolysers are attracting interest. Several large projects are in early stages to power hydrogen electrolysers, particularly in the MENA region and China.

ANNEXES

ANNEXE 1: CUMULATIVE INSTALLED PV CAPACITY (MWP) FROM 1992 TO 2024

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
AUSTRALIA	7	9	11	13	16	19	23	25	29	34	39	46	52	61	70	82	105	187	571	1376	2416	3226	4092	5109	5985	7132	11586	16399	21091	26129	30368	34521	39810
AUSTRIA	1	1	1	1	2	2	3	4	5	6	10	17	21	24	26	28	32	53	95	187	363	626	785	937	1096	1269	1455	1702	2043	2782	3791	6394	8903
BELGIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	24	112	671	1108	2176	2870	3139	3245	3355	3535	3865	4310	5127	6273	7123	8221	10685	11663
CANADA	1	1	2	2	3	3	4	6	7	9	10	12	14	17	20	26	33	95	281	559	766	1211	1843	2519	2665	2913	3130	3388	3713	5752	6453	7276	7597
CHINA	0	0	0	0	0	0	0	0	11	16	34	44	54	62	72	92	132	292	792	3492	6692	17682	28322	43472	78022	130882	175142	205442	253642	308522	414067	691243	1048508
DENMARK	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	3	3	4	7	29	499	698	751	979	1060	1138	1254	1363	1626	2344	4098	4585	5293
FINLAND	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	3	5	7	9	9	9	9	20	37	80	134	214	313	417	686	1004	1249
FRANCE	2	2	2	3	4	6	8	9	11	14	17	21	24	26	38	76	218	440	1446	3562	4906	5692	6837	7920	8636	9713	10755	11930	13098	16737	19703	23669	29679
GERMANY	6	9	12	18	28	42	54	70	114	176	296	435	1105	2056	2899	4170	6120	10566	18006	25916	34077	36710	37900	39224	40679	42293	45181	49016	54602	60314	67872	83204	100424
INDIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	272	1299	2384	3249	5436	9547	22561	33363	43431	47826	61490	79625	92645	124555
ISRAEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	22	67	186	272	377	588	772	878	953	1359	1961	2415	3350	4508	5658	6558
ITALY	9	12	14	16	16	17	18	18	19	20	22	26	31	38	50	100	496	1277	3605	13144	16799	18201	18610	18918	19300	19700	20125	20883	21668	22613	25083	30338	37002
JAPAN	19	24	31	43	60	91	133	209	330	453	637	860	1132	1422	1708	1919	2144	2627	3618	4914	6632	13599	23339	34151	42041	49501	56163	63193	71868	78414	85067	91417	97169
KOREA	0	0	0	0	0	0	0	0	0	0	5	6	9	14	36	81	357	524	650	729	1024	1555	2481	3615	4502	5835	8099	12665	17323	21199	24477	28158	30658
MALAYSIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	4	38	149	216	277	355	404	922	1421	1929	2301	3256	4120	5429
MOROCCO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	205	206	206	699	986	1714	2442
NETHERLANDS	0	0	0	0	0	1	1	1	5	9	16	22	40	43	45	49	59	69	111	170	390	767	1069	1536	2061	2914	4609	7225	10717	14349	18549	23337	26737
NORWAY	0	0	0	0	0	0	0	6	6	6	6	7	7	7	8	8	8	9	9	10	10	11	13	15	27	44	70	121	161	202	352	656	822
PORTUGAL	0	0	0	0	0	0	0	0	0	1	2	2	3	3	3	18	71	111	136	177	246	301	420	456	521	587	675	909	1079	1650	2608	3893	5369
SOUTH AFRICA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	312	1392	1486	2076	2145	2205	2668	3968	4426	4538	7503	8738
SPAIN	0	0	0	0	0	0	0	0	0	3	6	14	25	52	150	742	4021	4070	4595	5080	5439	5566	5641	5687	5742	5892	6270	11592	15809	21469	29964	38951	48353
SWEDEN	1	1	1	2	2	2	2	3	3	3	3	4	4	4	5	6	8	9	11	15	23	42	77	125	184	269	429	720	1120	1619	2462	4139	5073
SWITZERLAND	5	6	7	8	10	11	13	14	16	18	20	22	24	28	30	37	49	80	125	223	437	755	1061	1394	1664	1906	2173	2498	2973	3651	4734	6374	8172
THAILAND	0	0	0	0	0	0	0	0	0	0	0	0	0	25	32	32	32	42	48	242	387	824	1299	1420	2447	3057	3513	3529	3578	4088	4288	8875	11875
TÜRKIYE	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	6	32	64	358	1175	4206	7339	8551	9424	10917	12526	17353	21502
UK	0	0	0	0	0	0	0	0	1	2	3	5	7	10	14	18	23	33	96	997	1772	2891	5480	9655	11811	12756	13055	13328	13612	14002	14722	15983	17889
USA	0	0	0	0	0	0	0	0	0	0	0	0	111	190	295	455	753	1188	2017	3937	7130	12076	18321	25821	40956	51801	62481	76257	95533	120351	143046	177938	225015
REST OF EU COUNTRIES	0	0	0	0	0	0	0	0	0	0	0	11	21	23	33	41	106	674	2658	3758	5962	8403	8815	9166	9571	9943	10735	12369	16581	22740	31675	47856	62200
TOTAL IEA PVPS	50	66	82	106	140	195	259	365	559	771	1130	1554	2687	4108	5547	8009	14887	23047	40120	71164	100469	137237	175919	223823	296573	393760	486736	578109	694192	839650	1047727	1469490	1998685
BRAZIL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	38	53	66	86	93	1160	2416	4697	8474	14504	25371	37817	52137
TOTAL NON IEA PVPS	0	0	9	9	10	11	12	13	14	21	27	36	45	55	72	97	138	242	463	1088	1783	2923	4505	7399	11296	17442	33664	55823	85813	113699	147180	190302	262234
TOTAL	50	66	90	115	150	206	271	378	573	792	1158	1591	2732	4163	5619	8106	15025	23289	40582	72252	102252	140159	180424	231222	307869	411202	520400	633931	780005	953349	1194907	1659792	2260919

SOURCE IEA PVPS & OTHERS

ANNEXES / CONTINUED

ANNEXE 2: ANNUAL INSTALLED PV CAPACITY (MW) FROM 1992 TO 2024

COUNTRIES	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
AUSTRALIA	7	2	2	2	3	3	4	3	4	4	6	6	7	8	10	12	22	83	383	806	1039	811	866	1018	876	1147	4454	4813	4692	5038	4239	4153	5289
AUSTRIA	1	0	0	0	0	0	1	1	1	1	4	6	4	3	2	2	5	20	43	92	176	263	159	152	159	173	186	247	341	739	1009	2603	2509
BELGIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	18	88	559	437	1068	694	269	106	110	180	330	445	817	1146	850	1098	2464	978
CANADA	1	0	0	0	1	1	1	1	1	2	1	2	2	3	4	5	7	62	187	277	208	445	633	675	146	249	217	258	325	2038	701	823	321
CHINA	0	0	0	0	0	0	0	0	11	5	19	10	10	8	10	20	40	160	500	2700	3200	10990	10640	15150	34550	52860	44260	30300	48200	54880	105545	277176	357265
DENMARK	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	3	22	470	199	53	228	81	78	116	109	264	718	1754	487	708
FINLAND	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	2	2	0	0	0	11	17	43	53	81	98	104	269	318	245
FRANCE	2	0	0	1	2	2	2	2	2	3	3	4	3	2	12	38	143	222	1006	2116	1344	786	1145	1083	716	1077	1042	1175	1168	3639	2966	3966	6010
GERMANY	6	3	3	6	10	14	12	16	44	62	120	139	670	951	843	1271	1950	4446	7440	7910	8161	2633	1190	1324	1455	1614	2888	3835	5586	5712	7558	15332	17220
INDIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	214	1027	1085	865	2186	4111	13013	10803	10068	4395	13664	18135	13020	31910
ISRAEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	21	45	119	86	105	211	184	106	75	406	602	454	935	1158	1150	900
ITALY	9	4	2	2	0	1	1	1	1	1	2	4	5	7	13	50	396	781	2328	9539	3655	1402	409	308	382	400	425	758	785	944	2470	5255	6682
JAPAN	19	5	7	12	16	32	42	75	122	123	184	223	272	290	287	210	225	483	991	1296	1718	6968	9740	10811	7890	7460	6662	7030	8676	6545	6653	6350	5620
KOREA	0	0	0	0	0	0	0	0	0	0	5	1	3	5	22	45	276	167	127	79	295	531	926	1134	887	1333	2265	4566	4658	3876	3278	3681	2500
MALAYSIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	34	111	67	61	78	49	517	499	508	372	955	865	1309
MOROCCO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	205	1	0	493	287	728	728
NETHERLANDS	0	0	0	0	0	0	0	0	4	3	8	6	18	4	2	3	10	10	42	59	220	377	302	467	525	853	1695	2616	3492	3632	4200	4788	3400
NORWAY	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	1	0	1	1	2	2	11	18	26	51	40	41	150	303	166
PORTUGAL	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	14	53	40	25	41	69	55	119	36	65	66	88	234	170	571	958	1285	1476
SOUTH AFRICA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	305	1081	94	590	69	60	463	1300	458	112	2965	1235
SPAIN	0	0	0	0	0	0	0	0	0	3	3	8	11	27	98	592	3279	49	525	485	359	127	75	46	55	150	378	5322	4217	5660	8495	8987	8665
SWEDEN	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	2	4	8	19	35	48	59	85	160	291	400	499	842	1677	934
SWITZERLAND	5	1	1	1	2	2	2	2	2	2	2	2	2	4	2	7	12	30	46	98	214	319	306	333	270	242	267	325	475	677	1084	1640	1798
THAILAND	0	0	0	0	0	0	0	0	0	0	0	0	0	25	7	0	0	10	6	194	145	437	475	122	1027	610	456	16	49	510	200	4587	3000
TÜRKIYE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	26	32	294	818	3031	3133	1212	874	1492	1610	4827	4149
UK	0	0	0	0	0	0	0	0	1	1	1	2	2	3	4	4	5	10	63	901	776	1119	2589	4175	2155	945	299	273	284	391	720	1261	1906
USA	0	0	0	0	0	0	0	0	0	0	0	0	111	79	105	160	298	435	829	1920	3193	4946	6245	7500	15135	10845	10680	13776	19276	24819	22695	34892	47077
REST OF EU COUNTRIES	0	0	0	0	0	0	0	0	0	0	0	10	10	2	11	7	65	568	1984	1100	2204	2441	412	352	405	372	792	1634	4212	6159	8935	16181	15195
TOTAL IEA PVPS	50	16	16	24	34	55	64	106	194	212	359	424	1132	1421	1439	2463	6878	8160	17072	31044	29305	36768	38682	47904	72750	97187	92976	91372	116084	145458	208077	421763	529195
BRAZIL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	12	15	14	20	7	1067	1256	2281	3777	6030	10867	12446	14320
TOTAL NON IEA PVPS	**0**	**0**	**9**	**0**	**1**	**1**	**1**	**1**	**1**	**7**	**7**	**9**	**9**	**9**	**18**	**25**	**41**	**103**	**221**	**625**	**696**	**1139**	**1582**	**2894**	**3896**	**6147**	**16222**	**22158**	**29990**	**27886**	**33481**	**43122**	**71932**
TOTAL	**50**	**16**	**25**	**25**	**35**	**56**	**65**	**107**	**195**	**219**	**366**	**433**	**1141**	**1431**	**1456**	**2487**	**6919**	**8264**	**17293**	**31669**	**30000**	**37907**	**40264**	**50798**	**76647**	**103333**	**109198**	**113531**	**146074**	**173344**	**241558**	**464885**	**601127**

ANNEXES / CONTINUED

ANNEXE 3: AVERAGE 2024 EXCHANGE RATES

COUNTRY	CURRENCY CODE	EXCHANGE RATE IN 2024 (1 USD =)
AUSTRALIA	AUD	1.516
AUSTRIA	EUR	0.924
BELGIUM	EUR	0.924
BRAZIL	BRL	5.392
CANADA	CAD	1.370
CHILE	CLP	919.000
CHINA	CNY	7.189
DENMARK	DKK	6.896
FINLAND	EUR	0.924
FRANCE	EUR	0.924
GERMANY	EUR	0.924
INDIA	INR	83.677
ISRAEL	ILS	3.701
ITALY	EUR	0.924
JAPAN	JPY	151.353
KOREA	KRW	1364.153
MALAYSIA	MYR	4.680
MEXICO	MXN	18.330
MOROCCO	MAD	9.937
NETHERLANDS	EUR	0.924
NORWAY	NOK	10.756
PAKISTAN	PKR	278.570
PORTUGAL	EUR	0.924
SOUTH AFRICA	ZAR	18.326
SPAIN	EUR	0.924
SWEDEN	SEK	10.577
SWITZERLAND	CHF	0.881
THAILAND	THB	35.267
TÜRKIYE	TRY	32.867
UK	GBP	0.783
USA	USD	1.000

ANNEXES / CONTINUED

ANNEXE 4: COUNTRY AND MARKET GROUPINGS

COUNTRY/MARKET	SUB REGION	REGION
ALBANIA	ROW	OTHER COUNTRIES
ALGERIA	MIDDLE EAST AND AFRICA	OTHER COUNTRIES
ARGENTINA	THE AMERICAS	OTHER COUNTRIES
AUSTRALIA	ASIA PACIFIC	OTHER IEA PVPS COUNTRIES
AUSTRIA	EUROPE	EUROPEAN UNION
BANGLADESH	ROW	OTHER COUNTRIES
BELARUS	ROW	OTHER COUNTRIES
BELGIUM	EUROPE	EUROPEAN UNION
BOSNIA HERZEGOVINA	ROW	OTHER COUNTRIES
BRAZIL	THE AMERICAS	OTHER COUNTRIES
BULGARIA	EUROPE	EUROPEAN UNION
CANADA	THE AMERICAS	OTHER IEA PVPS COUNTRIES
CHILE	THE AMERICAS	OTHER COUNTRIES
CHINA	ASIA PACIFIC	CHINA
CHINESE TAIPEI	ASIA PACIFIC	OTHER COUNTRIES
COLOMBIA	THE AMERICAS	OTHER COUNTRIES
CROATIA	EUROPE	EUROPEAN UNION
CYPRUS	EUROPE	EUROPEAN UNION
CZECH REPUBLIC	EUROPE	EUROPEAN UNION
DENMARK	EUROPE	EUROPEAN UNION
ECUADOR	THE AMERICAS	OTHER COUNTRIES
EGYPT	MIDDLE EAST AND AFRICA	OTHER COUNTRIES
ESTONIA	EUROPE	EUROPEAN UNION
FINLAND	EUROPE	EUROPEAN UNION
FRANCE	EUROPE	EUROPEAN UNION
GERMANY	EUROPE	EUROPEAN UNION
GREECE	EUROPE	EUROPEAN UNION
HONDURAS	THE AMERICAS	OTHER COUNTRIES
HUNGARY	EUROPE	EUROPEAN UNION
ICELAND	EUROPE	OTHER COUNTRIES
INDIA	ASIA PACIFIC	INDIA
INDONESIA	ASIA PACIFIC	OTHER COUNTRIES
IRAN	MIDDLE EAST AND AFRICA	OTHER COUNTRIES
IRELAND	EUROPE	EUROPEAN UNION
ISRAEL	MIDDLE EAST AND AFRICA	OTHER IEA PVPS COUNTRIES
ITALY	EUROPE	EUROPEAN UNION
JAPAN	ASIA PACIFIC	JAPAN
JORDAN	MIDDLE EAST AND AFRICA	OTHER COUNTRIES
KAZAKHSTAN	ASIA PACIFIC	OTHER COUNTRIES
KOREA	ASIA PACIFIC	OTHER IEA PVPS COUNTRIES
KOSOVO	ROW	OTHER COUNTRIES
LATVIA	EUROPE	EUROPEAN UNION
LITHUANIA	EUROPE	EUROPEAN UNION
LUXEMBOURG	EUROPE	EUROPEAN UNION
MALAYSIA	ASIA PACIFIC	OTHER IEA PVPS COUNTRIES
MALTA	EUROPE	EUROPEAN UNION
MEXICO	THE AMERICAS	OTHER COUNTRIES
MONTENEGRO	ROW	OTHER COUNTRIES
MOROCCO	MIDDLE EAST AND AFRICA	OTHER IEA PVPS COUNTRIES
NETHERLANDS	EUROPE	EUROPEAN UNION
NORTH MACEDONIA	ROW	OTHER COUNTRIES
NORWAY	EUROPE	OTHER IEA PVPS COUNTRIES
PAKISTAN	ASIA PACIFIC	OTHER COUNTRIES
PANAMA	ROW	OTHER COUNTRIES
PERU	THE AMERICAS	OTHER COUNTRIES
PHILIPPINES	ASIA PACIFIC	OTHER COUNTRIES
POLAND	EUROPE	EUROPEAN UNION
PORTUGAL	EUROPE	EUROPEAN UNION
QATAR	ROW	OTHER COUNTRIES
REPUBLIC OF MOLDOVA	ROW	OTHER COUNTRIES
ROMANIA	EUROPE	EUROPEAN UNION
ROW	ROW	OTHER COUNTRIES
RUSSIA	EUROPE	OTHER COUNTRIES
SAUDI ARABIA	MIDDLE EAST AND AFRICA	OTHER COUNTRIES
SERBIA	EUROPE	OTHER COUNTRIES
SINGAPORE	ASIA PACIFIC	OTHER COUNTRIES
SLOVAKIA	EUROPE	EUROPEAN UNION
SLOVENIA	EUROPE	EUROPEAN UNION
SOUTH AFRICA	MIDDLE EAST AND AFRICA	OTHER IEA PVPS COUNTRIES
SPAIN	EUROPE	EUROPEAN UNION
SUDAN	ROW	OTHER COUNTRIES
SWEDEN	EUROPE	EUROPEAN UNION
SWITZERLAND	EUROPE	OTHER IEA PVPS COUNTRIES
THAILAND	ASIA PACIFIC	OTHER IEA PVPS COUNTRIES
TUNISIA	ROW	OTHER COUNTRIES
TÜRKIYE	EUROPE	OTHER IEA PVPS COUNTRIES
UAE	MIDDLE EAST AND AFRICA	OTHER COUNTRIES
UK	EUROPE	EUROPEAN UNION
UKRAINE	EUROPE	OTHER COUNTRIES
USA	THE AMERICAS	USA
VIETNAM	ASIA PACIFIC	OTHER COUNTRIES

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Technology Collaboration Programme

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