Technology Collaboration Programme
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International Energy Agency
**Photovoltaic Power Systems Programme**


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Task 1 Strategic PV Analysis and Outreach

PVPS

# TRENDS IN PHOTOVOLTAIC APPLICATIONS
## 2023

**REPORT IEA PVPS T1-43:2023**

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 2023 are Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, South Korea, Malaysia, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Türkiye, and the United States of America. The European Commission, Solar Power Europe, the Smart Electric Power Alliance (SEPA), the Solar Energy Industries Association, the Solar Energy Research Institute of Singapore and Enercity SA are also members.

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## AUTHORS

**Main Authors:** Gaëtan Masson, (Becquerel Institute), Melodie de l'Epine (Becquerel Institute France) Izumi Kaizuka (RTS Corporation)

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

**Data:** IEA PVPS Reporting Countries, Becquerel Institute (BE), RTS Corporation (JP) and Arnulf Jaeger-Waldau (EU-JRC), For the non-IEA PVPS countries Becquerel Sweden. For the other European Union countries: EU-JRC.

**Editor:** Gaëtan Masson, IEA PVPS Task 1 Operating Agent.

**Design:** Boheem

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**ISBN** Trends in Photovoltaic Applications 2023.

# 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 26th international survey. It provides an overview of PV power systems applications, markets and production in the reporting countries and elsewhere at the end of 2022 and analyses trends in the implementation of PV power systems between 1992 and 2022. 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 PV market passed the 1 TW mark in 2022 with 1 183 GW of PV power plants producing electricity worldwide at the end of the year, of which more than half was installed during the past four years. The annual PV market reached 236 GW worldwide in 2022, up 35% on the 2021 annual capacity, and this year a record 24 countries installed more than one GW, several of them for the first time. Growth across all regional markets (except the Middle East and Africa) is a sign of widespread competitiveness from high electricity prices and/or political support despite increased module prices through most of the year.

As the effects of climate change become more tangible, the fraction of electricity provided from PV (1 538 TWh  or 6.2% of the global electricity production in 2022) will inevitably increase as investments in low CO2 options continue – in 2022 nearly three quarters of new renewable generation capacity was PV, with an industrial value close to 100 billion USD. There was continued and significant investment in and ramping up of production and production capacities, with a global production capacity of 716 000 MW by the end of 2022, although just half of that is in operation. The world market is not far from a structural supply capacity of 1 TW per year, with strong growth in employment and an estimated 5.8 million jobs worldwide, both in upstream manufacturing and downstream installation. Growth in generation capacity is also stimulated by the electrification of the transport and heating sectors, and growing market segments ranging from green hydrogen to agrivoltaics.

Whilst 2022 saw a general increase in tender bids in Europe and few low tender bids elsewhere, competitiveness was a key market driver. The effects on gas supplies of the war in Ukraine and sanctions on Russia were felt across Europe and as far afield as Australia, driving gas, and hence electricity prices to highs that shut down or forced price caps in some electricity markets. With higher market prices, electricity from PV grew in value, both for utility scale and distributed generation, driving competitiveness and increasing confidence in power purchase agreements and self-consumption investments. As a consequence, support mechanisms in several countries were adjusted and those countries that had adopted Contract for Difference mechanisms were able to reduce expenditure – or even generate income as in France, with 761 million USD going into the national budget.

The societal implications of accelerating PV markets are wide, with growing questions around the social and environmental acceptability of utility scale systems in many countries, that call for a more transparent and sensitive approach to public consultation and education.

Market growth has been restricted in some countries as grid congestion, curtailment and staffing levels become an increasingly important factor affecting both deployment and competitiveness. As PV penetration rates increase due to market and political demand, governments, transmission and distribution service operators and the PV industry will need to work together to find viable solutions to finance and deploy grid infrastructure upgrades and technical and non-technical policies to increase grid capacity.

In 2022 PV has demonstrated its ability to provide key services to society in the form of secure and affordable electricity supply and low carbon tools for the energy transition. With significant investments in manufacturing capacity, we are at the dawn of the TeraWatt era.

**Gaëtan Masson**
Manager Task 1
IEA PVPS Programme

**Daniel Mugnier**
Chair
IEA PVPS Programme

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**PHOTOVOLTAIC POWER SYSTEMS PROGRAMME** WWW.IEA-PVPS.ORG

## TOTAL BUSINESS VALUE IN PV SECTOR IN 2022

**$230** BILLION USD

## TOP 5

## PV MARKETS IN 2022

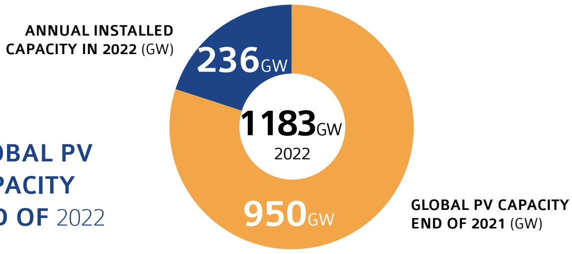
| | |
|---|---|
| CHINA | 105.5 GW |
| EU | 40.0 GW |
| USA | 21.1 GW |
| INDIA | 18.1 GW |
| BRAZIL | 9.9 GW |

## PV CONTRIBUTION TO ELECTRICITY DEMAND

**6.2%**

Share of PV in the global electricity demand in 2022

## GLOBAL PV CAPACITY END OF 2022

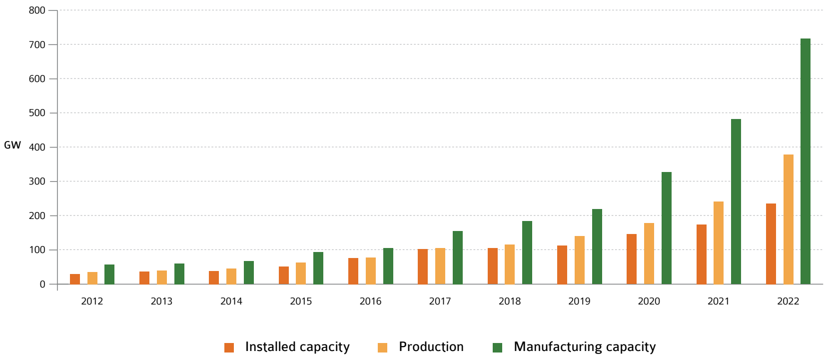


## CLIMATE CHANGE IMPACTS

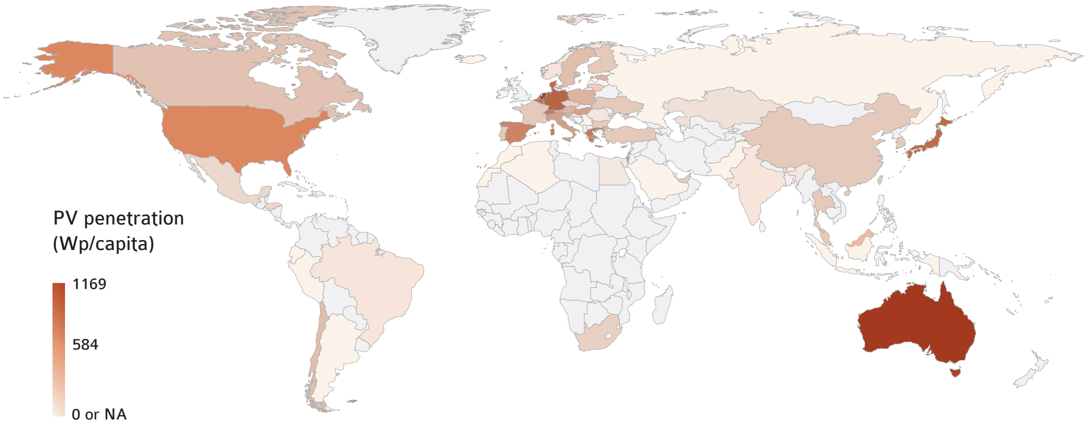
**1336**

million tons of $CO_2$ **saved** in 2022

**YEARLY PV INSTALLATION, MODULE PV PRODUCTION AND MODULE PRODUCTION CAPACITY 2012 - 2022** (GW)



## PV PENETRATION PER CAPITA IN 2022



**44 COUNTRIES**

REACHED AT LEAST

**1 GWp**

IN 2022

**PV POWER PER CAPITA**

1. AUSTRALIA (1 169 WP/CAP)
2. THE NETHERLANDS (1 031 WP/CAP)
3. GERMANY (800 WP/CAP)
4. BELGIUM (698 WP/CAP)
5. JAPAN (680 WP/CAP)

**24 COUNTRIES**

INSTALLED AT LEAST

**1 GWp**

IN 2022

SOURCE IEA PVPS & OTHERS

# one

# 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 (essential for grid-connected systems and required for most off-grid systems), 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 commonly considered by industrial actors to be an easy way to improve cell and module wattage. Until recently, wafer sizes ranged from 156.75 x 156.75 square mm (called M2 cells) up to 210 x 210 square mm (called G12 cells). However, in 2022, M10 wafers (182 x 182 square mm) and G12 have mostly pushed others sizes off the market, with a combined market share of around 82%. In general, cells can be classified as wafer-based crystalline silicon c-Si (mono- and multi-crystalline), compound semiconductor (thin-film), or organic.

Currently, c-Si technologies account for more than 97.5% 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 market is nearly exclusively composed of these cells, as they cover 97% of the c-Si share. Multicrystalline silicon (mc-Si) cells, also called polycrystalline, are formed with multicrystalline wafers, manufactured by a cast solidification process. They are still in production in rare instances because of their lower production prices. Nevertheless, they are less efficient, with an average conversion efficiency of approximately 18% - 21% in mass production (single-junction) and have nearly disappeared from the market.

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 copperindium-(gallium)-diselenide (CIGS and CIS). Amorphous (a-Si) and micromorph silicon (μ-Si) used to have a significant market share but failed to follow both the price of crystalline silicon cells and the efficiency increase of other thin film technologies.

## PV TECHNOLOGY / CONTINUED

Their efficiency ranges between 9% (OPV), 10% (a-Si), 17% (CIGS and CIS), 19% (CdTe), 25% GaAs (non-concentrated) and above 40% for some CSP modules.

Organic thin-film PV (OPV) cells use dye or organic semiconductors as the light-harvesting active layer. Organic and inorganic hybrid materials such as perovskites are also used for photovoltaic materials. This technology has generated increasing interest and research over the last few years and is currently the fastest-advancing solar technology. Despite the low production costs, stable products are not yet available for the market, nevertheless development and demonstration activities are underway. Tandem cells based on perovskites are an important focal point of current research, with either a crystalline silicon base or a thin film base and could hit the market sooner than pure perovskites products. In 2022, perovskite solar cells achieved 32.5% efficiency in silicon-based tandems (up 4% since 2021) and 24.9% efficiencies in CIGS or CIS-based tandems. Several Chinese manufacturers have announced shipping perovskite modules in 2022.

Photovoltaic modules are typically rated from 350 W to 600 W, or even up to 740W in 2023 for bifacial glass modules, depending on the technology and the size – although typical size for residential systems in 2022 was 350 W to 435 W, with larger modules above 540 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 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 have recently become more and more attractive for ground-mounted systems, particularly for systems in countries with a high share of direct irradiation. By using such systems, the energy yield can typically be increased by 10%-20% for single axis trackers and 20%-30% for double axis trackers compared with fixed systems.

## PV APPLICATIONS AND MARKET SEGMENTS

When considering distributed PV systems, it is necessary to distinguish BAPV (building applied photovoltaics) and BIPV (buildings integrated photovoltaics) systems. BAPV refers to PV systems installed on an existing building while BIPV implies that the PV replaces conventional building materials such as roofing elements or facades. 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 be manufactured using various materials, although a vast majority use glass on both sides. They can be assembled in a way that they fill multiple functions have multiple functions usually filled by conventional building envelope solutions.

Bifacial PV modules collect light on both sides of the panel. Depending on the reflection off the ground underneath the modules (albedo), the energy production increase is estimated to a maximum of 15% with a fixed structure, and possibly up to 30-35% with a single-axis system. Bifacial modules have a growing competitive advantage despite higher overall installation costs. The factors determining the performance of bifacial modules are increasingly better understood and integrated into downstream models and industry. Bifacial PV panels continued market penetration in 2022 with an increasing number of utility scale systems commissioning them.

Floating PV systems are mounted on a structure that floats on a water surface and can be associated with existing grid connections, for instance in the case of dam vicinity. The development of floating PV on man-made water areas is a solution to land scarcity in high population density areas and can be combined with hydropower, and can also be used to reduce evaporation rate in dry climates and improve cooling for better efficiency in warm climates.

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.

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

# PV APPLICATIONS AND MARKET SEGMENTS / CONTINUED

VIPV or vehicle integrated PV 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. VAPV or vehicle applied PV relates to the use of PV modules on vehicles without integration.

Various Solar Home Systems (SHS) or pico PV systems have experienced significant development in the last few years, combining 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, despite their higher initial cost, they present some advantages where array sizes are small and maximal performance is to be achieved. "AC modules" could see increasing use in residential systems but also linear PV systems where savings can be made on cable costs when using AC modules.

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.

Grid-connected centralised PV systems perform the functions of centralised power stations. The power supplied by such a system is physically not associated with an electricity customer, and the system is not located to specifically perform functions on the electricity network other than the supply of bulk power. 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 can mitigate fuel price increases, deliver operating cost reductions, and offer higher service quality than traditional single-source generation systems. The combining of technologies provides new possibilities to provide a reliable and cost-effective power source in remote places such as for telecom base stations for instance. 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 off-grid systems, a storage battery is required to provide energy during low-light periods. Nearly all batteries used for PV systems are of the deep discharge lead-acid type. Other types of batteries (e. g. NiCad, NiMH, Li-Ion) are also suitable and have the advantage that they cannot be overcharged or deep-discharged. The lifetime of a battery varies, depending on the operating regime and conditions, but is typically between 5 and 10 years even if progresses are seen in that field.

A charge controller (or regulator) is used to maintain the battery at the highest possible state of charge (SOC) 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 "stand-alone 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.

# PV APPLICATIONS AND MARKET SEGMENTS / CONTINUED

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.

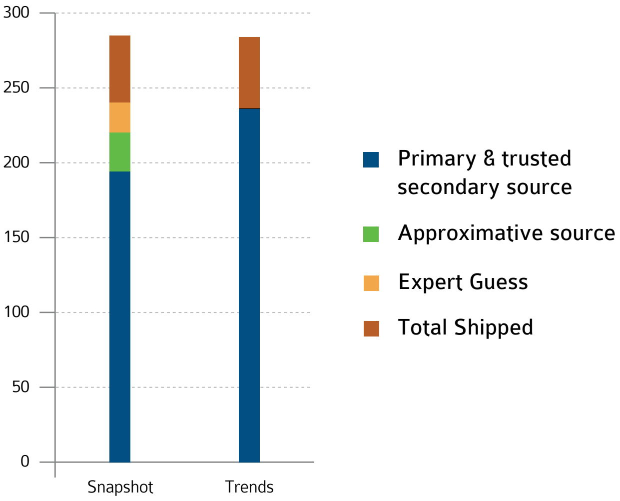
## METHODOLOGY FOR THE MAIN PV MARKET DEVELOPMENT INDICATORS

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). Some countries report the power output of the PV inverter (device converting DC power from the PV system into AC electricity compatible with standard electricity networks). 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). Conversion of AC data has been made when necessary, to calculate the most precise installation numbers every year. 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 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 (plug&play systems with only a few modules), whilst not significant in overall volumes is symptomatic of the development of unreported systems reaching the market and sometimes being invisible to distribution system operators and data collection.

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 takes into account reported and expert estimates of new commissioned capacity as well as probable unreported volumes installed in one of the above contexts. Data on estimated shipped capacity, in inventories, has been incorporated in Figure 1.1 to improve market visibility. As can be seen, between estimations published in the Snapshot in April 2023 and those in this publication, many countries have firmed their evaluation of annual installed volumes. In particular, a more comprehensive understanding of the Chinese market reporting conventions leads to a more coherent evaluation of 2022 DC volumes at 105.5 GWdc (just below first estimates at 106 GWdc), whilst revised data for a number of European countries has lowered estimated capacity there slightly.

**FIGURE 1.1**: ANNUAL INSTALLED VS ANNUAL SHIPPED VOLUMES AND EVOLUTION OF DATA ESTIMATIONS



SOURCE IEA PVPS & OTHERS

# two

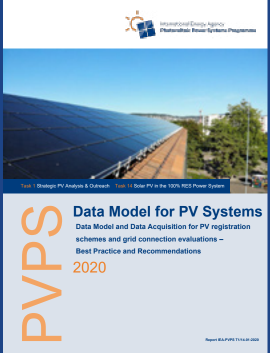
# PV MARKET DEVELOPMENT TRENDS

Since the beginning and the earliest development of the PV market, over 1 183 GW of PV plants have been installed globally, of which around 65% has been installed in the past five years. Over the years, a growing number of markets have started to contribute to global PV installations, and the year 2022 closed with a record number of new countries installing significant PV capacity.

A large majority of PV installations are grid-connected; these include an inverter that converts the variable direct current (DC) output of solar modules into alternating current (AC) to be fed into the electrical grid. PV installation data is reported in DC by default in this report (see also Chapter 1). When countries are reporting officially in AC, this report converts them to DC to maintain coherency. When official reporting is in AC, announced capacities may be specified as MWac or MWdc in this report when necessary. By default, MW implies capacities mentioned in DC.

For more information on registering PV installations, download the report.

Download the
"data Model for PV
System" reports



Technology Collaboration Programme

Task 1 Strategic PV Analysis & Outreach Task 14 Solar PV in the 100% RES Power System

PVPS

Data Model for PV Systems

Data Model and Data Acquisition for PV registration schemes and grid connection evaluations – Best Practice and Recommendations

2020

Report IEA-PVPS T1/14-01:2020

## THE GLOBAL INSTALLED CAPACITY

**Global cumulative installed capacity** (GW)

+24.9% YoY growth

At the end of 2022, the global PV installed capacity represented 1 183.4 GW of cumulative PV installations – slightly below the preliminary estimation of 1 185 GW published in the IEA-PVPS Snapshot of Global PV Markets 2023 in April of this year.

Presently, it appears that 235.8 GW represented the minimum capacity installed during 2022 with a reasonably firm level of certainty. This level is the highest ever recorded for PV installations, well above last year's installed capacity, despite continued perturbations from COVID, high module prices, trade disputes and grid congestion in an increasing number of countries.

The group of IEA PVPS countries represented 927.5 GW of the global installed capacity. The IEA PVPS participating countries in 2022 were Australia, Austria, Canada, Chile, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Republic of Korea[1], Malaysia, Mexico, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Türkiye, and the USA.

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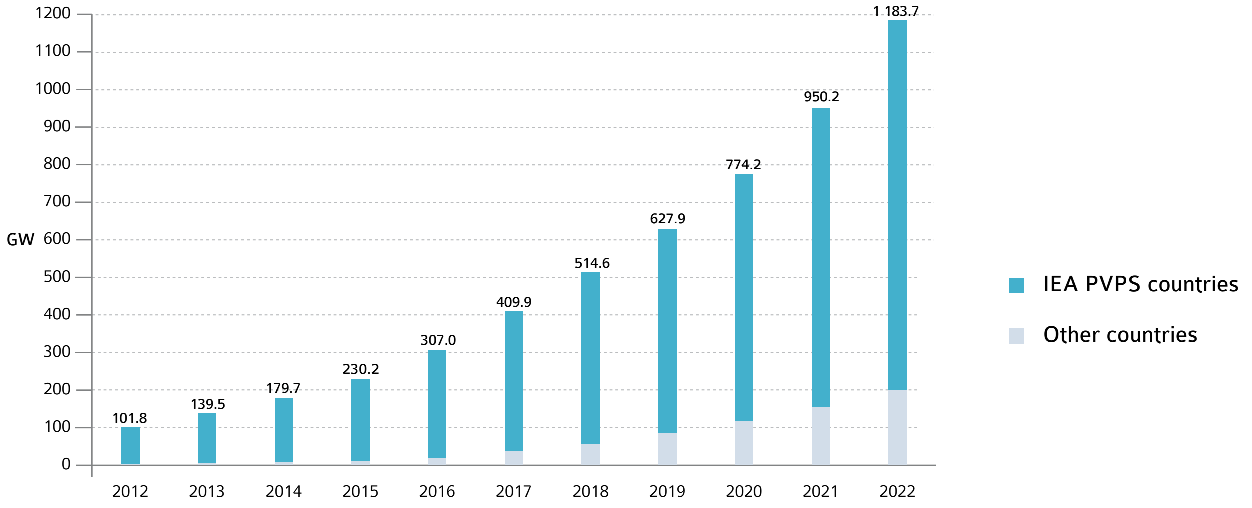
[1] The Republic of Korea is also commonly known as South Korea and that name is used elsewhere in this publication.

## THE GLOBAL PV INSTALLED CAPACITY / CONTINUED

Additionally, for the purpose of this report, the EC is a member of the IEA PVPS and, as such, its member countries are counted in IEA PVPS blocks. The other key markets that have been considered and which are not part of the IEA PVPS Programme, represented a total cumulative capacity of 256 GW at the end of 2022. Amongst them, **India** covered around one third of this capacity with 79 GW. **Vietnam** (18.5 GW but with very low newly installed capacity in 2022) and **Brazil** (plus 9.9 GW to reach 23.6 GW) were the non-IEA PVPS countries to have the most significant volumes. The remaining part of PV capacities is mainly located in Europe, and partly related to historical installations as well as to the contribution of emerging markets: **UK** with 15.2 GW, a dynamic **Poland** with 12.5 GW and **Belgium** (who exited the IEA PVPS program for 2022 but returns in 2023) at 8.1 GW are the largest cumulative markets. Several other European countries have GW cumulative capacities including **Greece** and **Ukraine** with over 6 GW, **Hungary** at approx. 4 GW, the **Czech Republic** with 2.3 GW installed, **Romania** with 1.9 GW, and **Bulgaria** at 1.4 GW. The other major country that accounted for the highest cumulative installations at the end of 2022 not part of IEA PVPS programmes in 2022 or 2023 is **Taiwan** with 9.7 GW. Numerous countries all over the world have started to deploy PV, but few have yet reached a significant development level in terms of cumulative installed capacity outside the ones mentioned above. New developments occurred in the Middle East (**Jordan**, **UAE**) and previous developments in Africa which led to GW-scale cumulative installation levels: 3.6 GW in the **UAE**, 3.5 GW in **Egypt** and 1.9 GW in **Jordan** for instance.

**FIGURE 2.1**: EVOLUTION OF CUMULATIVE PV INSTALLATIONS



SOURCE IEA PVPS & OTHERS

### PV PENETRATION PER CAPITA

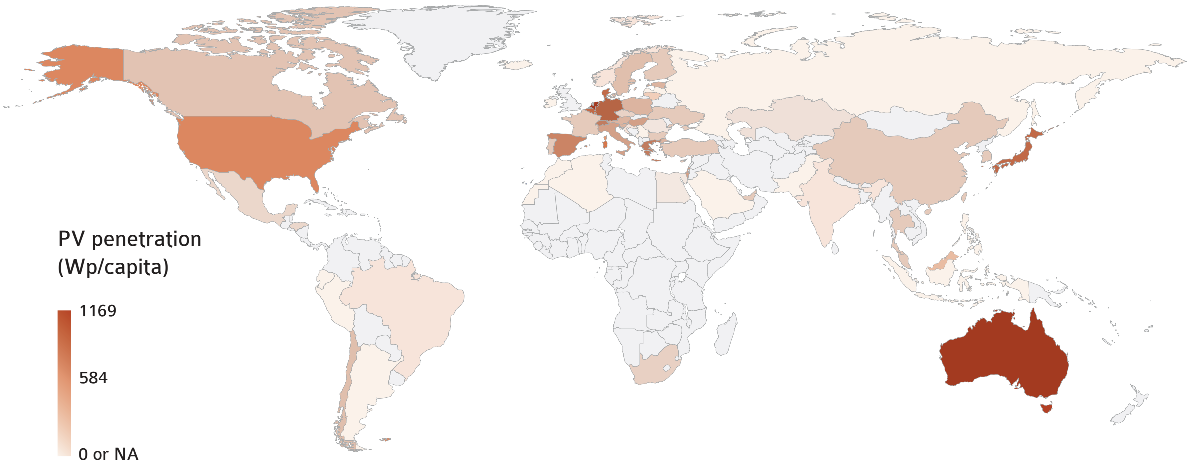
PV penetration can be measured either as a ratio of Wp per capita or kWh generated to meet a country's electricity demand – here we look at the volume of PV capacity relative to the country's population, indicating the relative efforts made by different countries.

In just a few years, **Australia** has reached the highest installed PV capacity per inhabitant with 1 169 W/cap (up 15% on 2021) in IEA-PVPS and surveyed countries. **The Netherlands** is second with 1 031 W/cap (+26%). **Germany** comes next with 800 W/cap followed by **Belgium** with 698 W/cap, overtaking **Japan** with 680 W/cap. Five more countries have over 500 W/cap: **Spain**, **Greece**, **Denmark**, **Switzerland** and **Malta**. Of the most populous countries, **USA** is leading with 425 W/cap, **China** follows at 293 W/cap, and despite a large market recently, **India** lags at only 56 W/cap.

In 2022, typical residential systems had modules with an individual power of 350 Wp to 435 Wp; we can say that in some countries one module per person has been installed whilst others are heading to the equivalent of two or three modules per person.

**Australia has reached the highest installed PV capacity per inhabitant with 1 169 W/cap.**

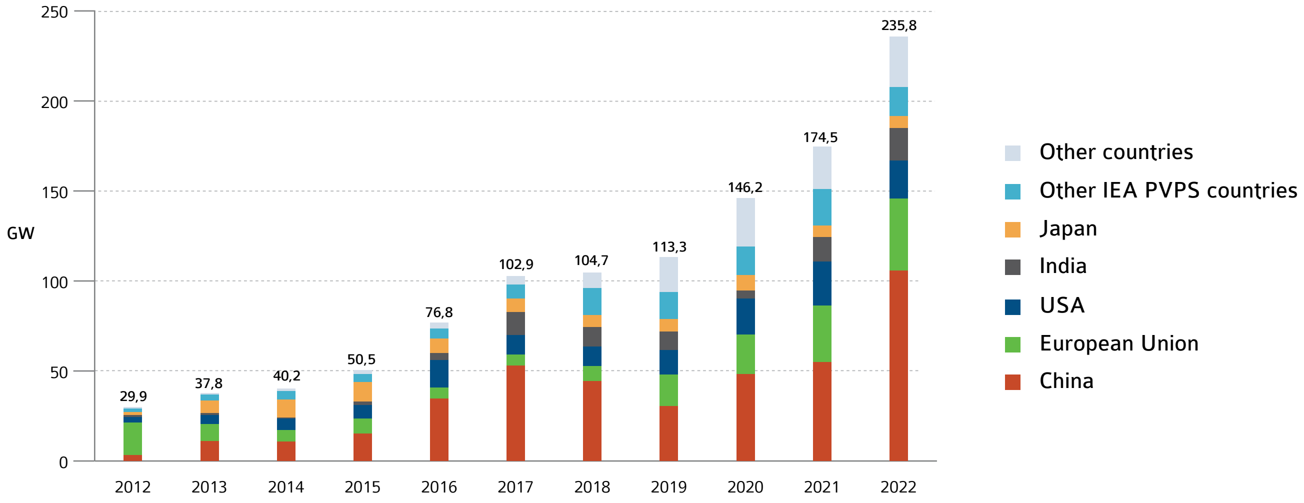
## FIGURE 2.2: PV PENETRATION PER CAPITA IN 2022



SOURCE IEA PVPS & OTHERS

## EVOLUTION OF PV ANNUAL INSTALLATIONS

## FIGURE 2.3: EVOLUTION OF ANNUAL PV INSTALLATIONS IN MAJOR MARKETS



SOURCE IEA PVPS & OTHERS

# THE GLOBAL PV INSTALLED CAPACITY / CONTINUED

The IEA PVPS countries[2] installed at least 178.9 GW in 2022. While they are more difficult to track with a high level of certainty, installations in non-IEA PVPS countries contributed an estimated amount of 56.8 GW. For the third year in a row, the global PV market experienced significant growth despite continued supply chain difficulties and high module prices, which could have paused or delayed market development in some countries. For some countries, numbers indicated in this report have been transformed to DC numbers to maintain the coherency of the overall report, and as such may differ to government published data.

As in previous years, **China**, in first place with exceptional growth, has nearly doubled 2021 volumes to install an unprecedented 105.5 GWdc in 2022, (converted from **China**'s National Energy Administration AC figures), with evenly balanced contributions from centralised and distributed systems. The Chinese market represented 45% of the global installation in 2022, whilst the total installed capacity in **China** reached 414 GW.

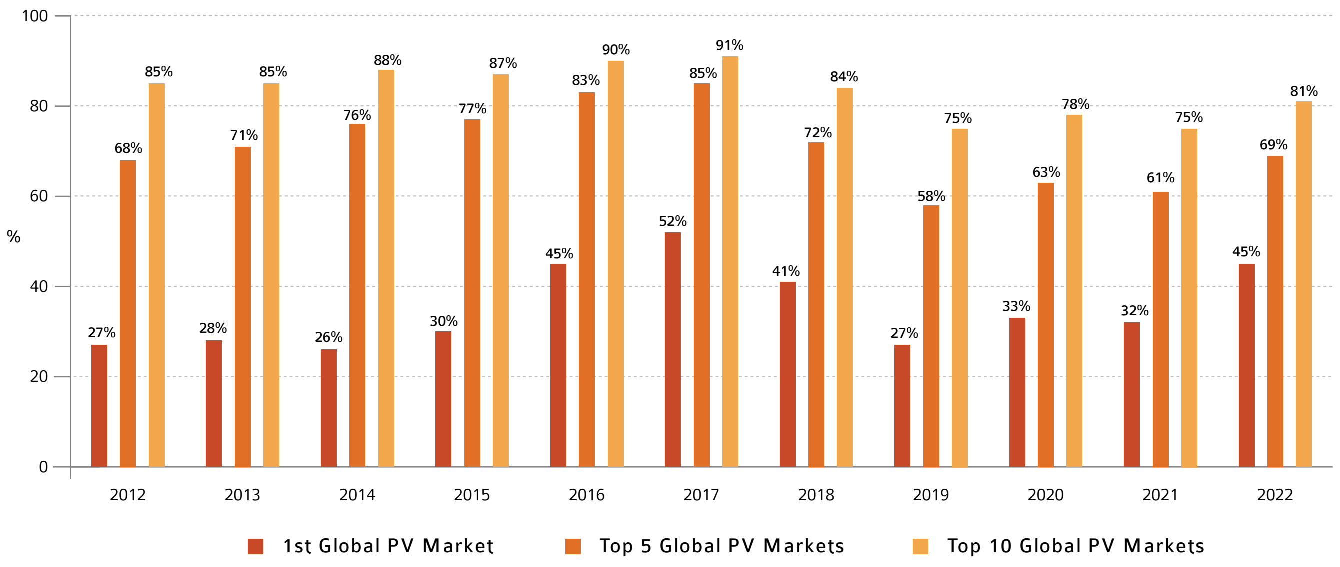
Counting individual countries, the **USA** is second with a smaller 2022 market of 21.1 GW (down from 2021's 24.1 GW but above preliminary Snapshot data of 18 GW) under the combined influence of trade issues and grid connection backlogs. The utility sector installations decreased (down to 12.5 GW from roughly 17 GW in 2021) however the residential market increased over 2021 installation levels. At the end of 2022, the **USA** reached 141.6 GW of cumulative installed capacity.

**India** was in third place with 18.1 GW installed, up from the previous year's 13 GW, for a total cumulative capacity of 79.1 GW.

Consolidating on 2021 volumes, **Brazil** appears now as one of the key global players, coming in 4th place, having an extremely dynamic market in 2022 with 9.9 GW (23.6 GW cumulative) installed, above the 5th placed **Spain** which saw 8.5 GW installed for a cumulative total of 29.9 GW.

Considered as a whole, the **European Union** would come in second, growing strongly for the fourth year in a row with 40 GW. **Spain** (8.5 GW) and **Germany** (7.2 GW) were the key markets in 2022 followed by **Poland** (4.9 GW), the **Netherlands** (3.9 GW) and several others.

**FIGURE 2.4**: EVOLUTION OF MARKET SHARE OF TOP COUNTRIES



SOURCE IEA PVPS & OTHERS

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[2] For the purpose of this report, IEA PVPS countries are those that are either member in their own right or through the adhesion of the EC.

Together, the five leading individual countries represented around 69% of all installations recorded in 2022. In terms of cumulative installed capacity, these countries represent 66% of the global capacity. This shows that the global PV market concentration is still very strong, with new markets contributing proportionally less to global installation numbers than established ones - and much of this is due to the overwhelming market lead by **China**, with 45% of new capacity in 2022.

Behind the top 5, **Germany** in 6th place, (7.2 GW in 2022 for 67.3 GW cumulative), **Japan** in 7th place with a steady 6.7 GW in 2022 to reach a total cumulative capacity of 85 GW is followed by **Poland** in 8th place, increasing on 2021's performance for 4.9 GW annual and a cumulative capacity of 12.5 GW. Rounding out the Top Ten, **Australia** in 9th place (4.2 GW in 2022, down from 4.9 GW in 2021, mostly due to supply chain issues. The total installed PV capacity reached 30.4 GW at the end of 2022) The strong growth of solar has allowed a regional network to function at 100% renewables over more than a week, a first on this scale. Rounding out the top 10, the **Netherlands** continues strongly with 3.9 GW for a total of 18.2 GW.

Together, these 10 markets cover around 81% of the 2022 annual world market, a sign that the growth of the global PV market has been driven by a limited number of countries 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. As shown in Figure 2.4, the market concentration steadily decreased in 2019 before growing again in 2020, stabilising in 2021 then growing even more in 2022, mostly 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, **China**'s installations maximized global growth.

The level of installations required to be included in the top 10 (country wise) has increased steadily since 2014: from 1.6 GW in 2018, to around 3.5 GW since 2020, nearly hitting 4 GW in 2022. This reflects the global growth trend of the solar PV market, but also its variations from one year to another.

**TABLE 2.1**: EVOLUTION OF TOP 10 MARKETS

| RANKING | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GERMANY | CHINA | CHINA | CHINA | CHINA | CHINA | CHINA | CHINA | CHINA | CHINA | CHINA |
| 2 | ITALY | JAPAN | JAPAN | JAPAN | USA | INDIA | INDIA | USA | USA | USA | USA |
| 3 | CHINA | USA | USA | USA | JAPAN | USA | USA | INDIA | VIETNAM | INDIA | INDIA |
| 4 | USA | GERMANY | UK | UK | INDIA | JAPAN | JAPAN | JAPAN | JAPAN | JAPAN | BRAZIL |
| 5 | JAPAN | ITALY | GERMANY | INDIA | UK | TÜRKIYE | AUSTRALIA | VIETNAM | GERMANY | GERMANY | SPAIN |
| 6 | FRANCE | UK | SOUTH AFRICA | GERMANY | GERMANY | GERMANY | TÜRKIYE | AUSTRALIA | AUSTRALIA | BRAZIL | GERMANY |
| 7 | AUSTRALIA | ROMANIA | FRANCE | SOUTH KOREA | THAILAND | SOUTH KOREA | GERMANY | SPAIN | SOUTH KOREA | AUSTRALIA | JAPAN |
| 8 | INDIA | INDIA | SOUTH KOREA | AUSTRALIA | KOREA | AUSTRALIA | MEXICO | GERMANY | INDIA | SPAIN | POLAND |
| 9 | GREECE | GREECE | AUSTRALIA | FRANCE | AUSTRALIA | BRAZIL | SOUTH KOREA | UKRAINE | SPAIN | SOUTH KOREA | AUSTRALIA |
| 10 | BULGARIA | AUSTRALIA | INDIA | CANADA | TÜRKIYE | UK | NETHERLANDS | SOUTH KOREA | NETHERLANDS | POLAND | NETHERLANDS |
| RANKING EU | 1 | 2 | 3 | 3 | 4 | 5 | 4 | 2 | 2 | 2 | 2 |
| MARKET LEVEL TO ACCESS THE TOP 10 | | | | | | | | | | | |
| | 843 MW | 792 MW | 779 MW | 675 MW | 818 MW | 944 MW | 1 621 MW | 3 130 MW | 3 492 MW | 3 710 MW | 3 900 MW |

**SOURCE** IEA PVPS & OTHERS

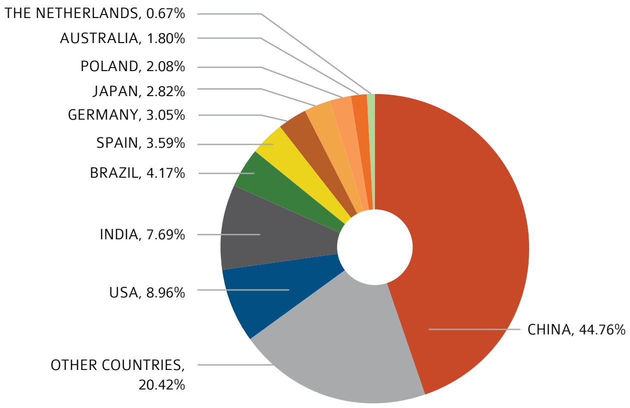
# THE GLOBAL PV INSTALLED CAPACITY / CONTINUED

As detailed previously, the IEA PVPS choice consists in reporting DC capacities. An estimate of AC capacities would put the new installed capacities number between 150 to 190 GW in 2022. 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.

Other countries that installed several GW in 2022 and were found in the top 10 countries in the past didn't succeed in maintaining a sufficiently high level of installations to stay in the rankings: **France**, **Italy**, **South Korea**, whilst a few other countries have installed several GW in the past, but either had smaller markets in 2022 (**Türkiye**, the **UK**, **Vietnam**) or have not been able to crack the top 10 markets yet (**Chile**). The fluctuations of the markets is a feature of the PV industry reacting to changes in policies and therefore in market development. This is levelling progressively with PV reaching competitiveness faster than many expected, and countries moving to unsubsidised PV, where the market becomes much more independent of policies and support mechanisms.

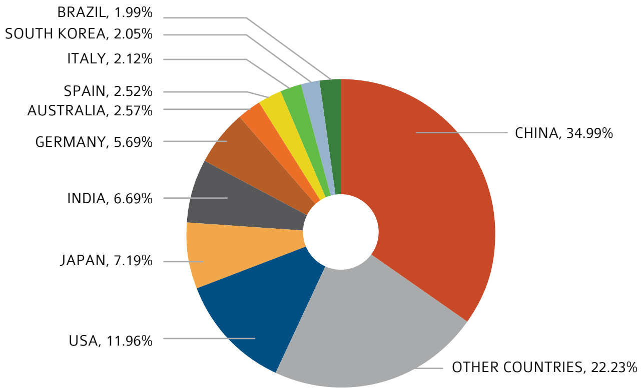
Other countries that installed significant amounts of PV, above the GW mark are mostly European countries - **Denmark**, **Greece**, **Switzerland**, **Belgium**, **Austria** and **Hungary**, however **Chile** in the Americas, **Israel** and **Türkiye** in the MENA regions and **Taiwan** and **Malaysia** in Asia also installed over 1 GW.

**FIGURE 2.5**: GLOBAL PV MARKET IN 2022



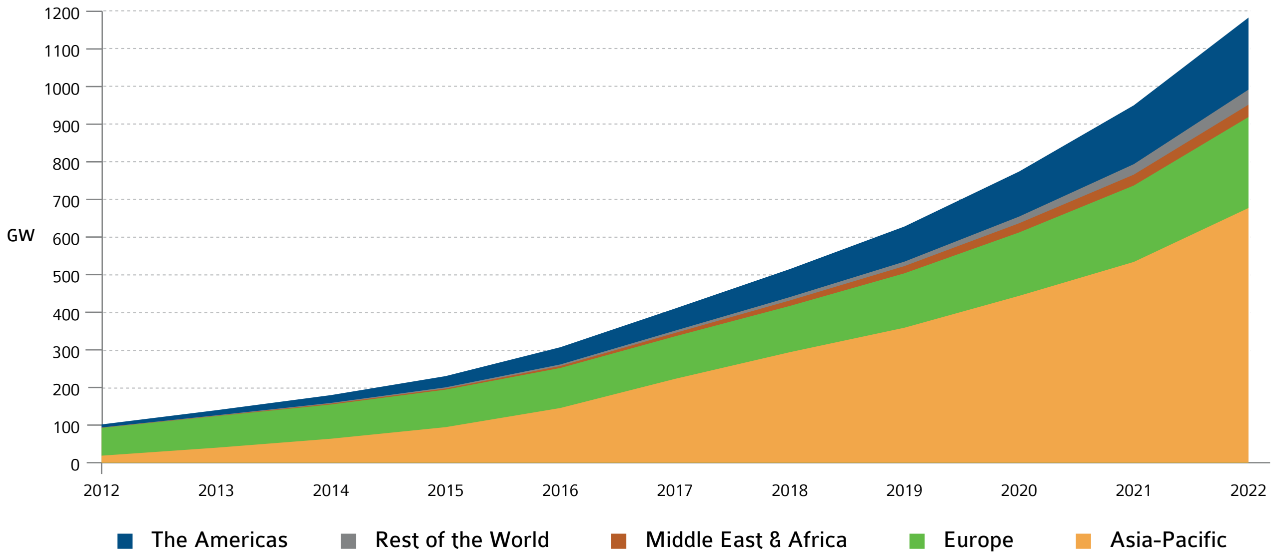
SOURCE IEA PVPS & OTHERS

**FIGURE 2.6**: CUMULATIVE PV CAPACITY END 2022



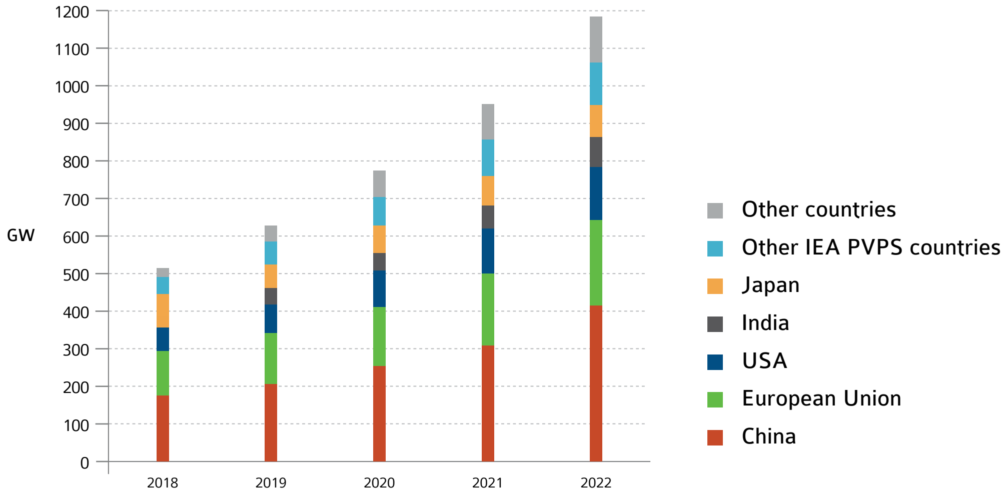
SOURCE IEA PVPS & OTHERS

**FIGURE 2.7**: EVOLUTION OF REGIONAL PV INSTALLATIONS



SOURCE IEA PVPS & OTHERS

**FIGURE 2.8**: 2018-2022 GROWTH PER MAJOR MARKET



SOURCE IEA PVPS & OTHERS

# PV MARKET SEGMENTS

Solar PV experienced another growth year, roughly equally driven by utility-scale projects (which continued to develop fast both in established markets and in countries which only appeared recently on the PV development map) and distributed systems, pushed by high consumer electricity prices and specific deployment programs, for example in **China**. National markets are very diverse, with significant imbalances between utility and distributed segments in many markets depending on previous and current policy priorities, however major markets such as **China**, **Japan**, the **Netherlands** and **France** are more balanced with both segments well developed.

The distributed capacity was again slightly below that installed in centralised systems, with 115 GW (51 GW from **China** alone) in 2022 after 80 GW in 2021 compared to 62 GW in 2020. Ground mounted utility-scale PV installations increased in 2022 with 120 GW, compared to 92 GW in 2021 and 84 GW in 2020, mainly driven by **China**, **India**, the **USA**, **Spain**, **South Korea** and emerging PV markets. The share of utility-scale still represented around 55% of cumulative installed capacity even though distributed PV grew even more significantly. Whilst 2022 saw low PV electricity prices in competitive tenders, they were generally up on 2021 prices and a number of tenders were undersubscribed as electricity markets and Power Purchase Agreements (PPAs) became more attractive. Off-grid and edge-of-the-grid applications are increasingly integrated in these two large categories.

Except for the European market that incentivized residential segments from the start, most of the major PV developments in emerging PV markets tend to come from utility-scale PV. This evolution has had different causes. Utility-scale PV requires developers and financing institutions to set up plants in a relatively short time. This option allows the start of using PV electricity in a country faster than what distributed PV requires. Moreover, tenders are making PV electricity even more attractive in some regions. However, both trends are compatible as some policies were implemented recently in emerging markets to incentivize rooftop installations and tenders for rooftop installations are being organized in several historical markets.

## UTILITY-SCALE PV

Utility-scale PV plants are in general ground-mounted (or floating) installations. In rare cases, they could be used for self-consumption when close to large consumption centres or industries, but generally they feed electricity directly into the grid.

**TABLE 2.2**: TOP 10 COUNTRIES FOR CENTRALISED PV INSTALLED IN 2022

| COUNTRY | GW |
|---|---|
| CHINA | 54.44 |
| INDIA | 13.95 |
| USA | 12.50 |
| SPAIN | 5.45 |
| JAPAN | 3.76 |
| GERMANY | 2.92 |
| SOUTH KOREA | 2.81 |
| BRAZIL | 2.52 |
| NETHERLANDS | 2.26 |
| FRANCE | 1.59 |

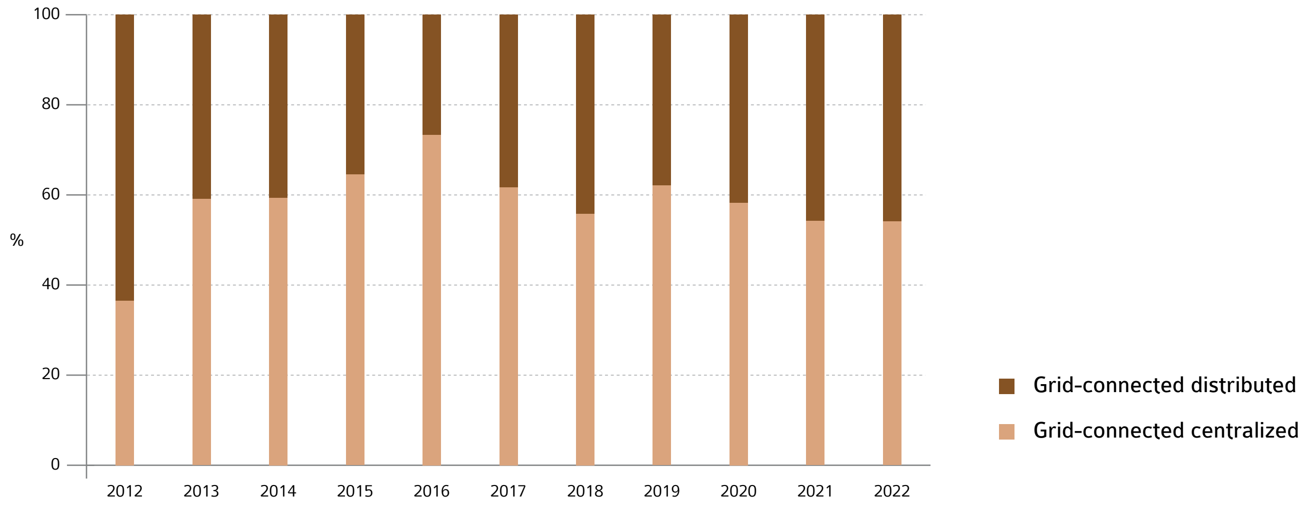
**SOURCE** IEA PVPS

**TABLE 2.3**: TOP 10 COUNTRIES FOR CUMULATIVE CENTRALISED PV INSTALLED CAPACITY IN 2022

| COUNTRY | GW |
|---|---|
| CHINA | 254.38 |
| USA | 89.93 |
| INDIA | 66.85 |
| JAPAN | 33.88 |
| SPAIN | 23.68 |
| SOUTH KOREA | 21.15 |
| GERMANY | 13.74 |
| NETHERLANDS | 10.75 |
| AUSTRALIA | 10.38 |
| FRANCE | 9.59 |

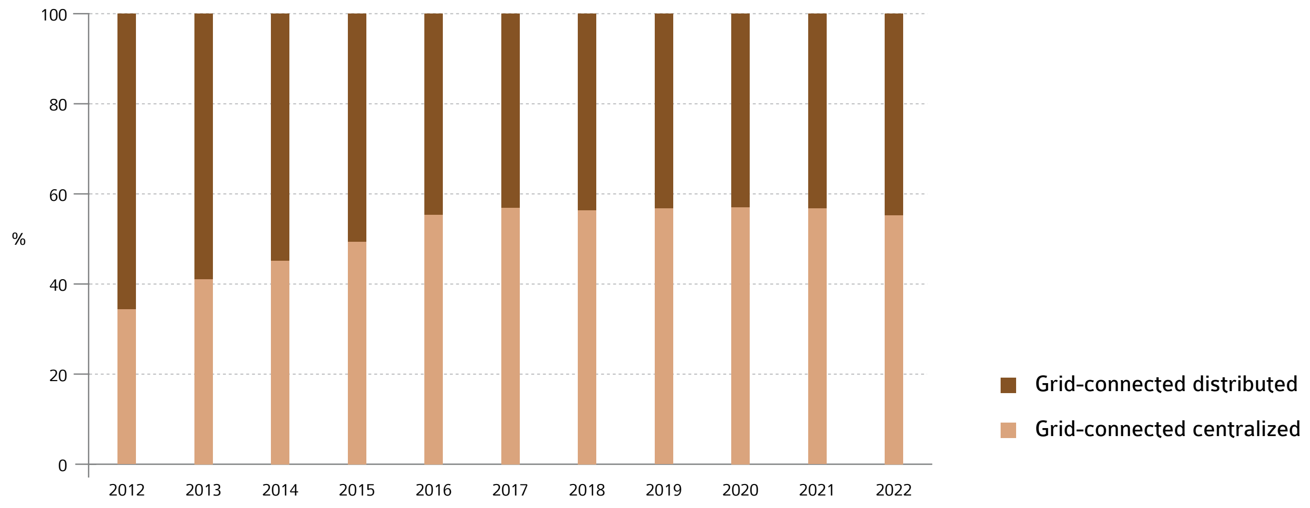
**SOURCE** IEA PVPS

**FIGURE 2.9**: ANNUAL SHARE OF CENTRALISED AND DISTRIBUTED GRID-CONNECTED INSTALLATIONS 2012-2022



SOURCE IEA PVPS & OTHERS

**FIGURE 2.10**: CUMULATIVE SHARE OF GRID CONNECTED PV INSTALLATIONS 2012-2022



SOURCE IEA PVPS & OTHERS

## PV MARKET SEGMENTS / CONTINUED

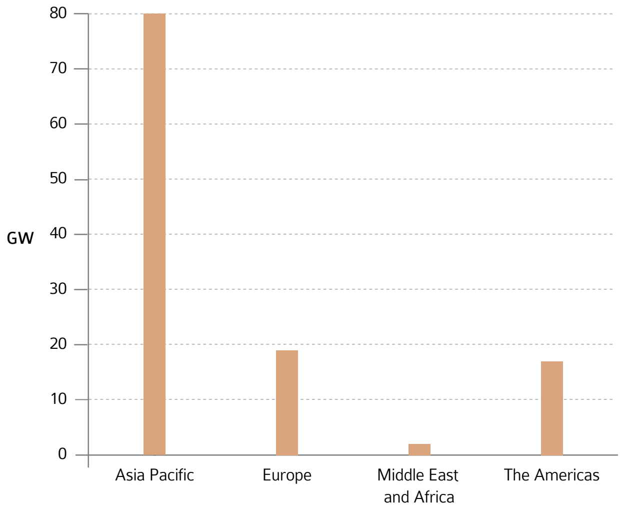
Utility-scale applications are thriving in both new and established PV markets. In new or maturing markets more countries are proposing tendering processes to select the most competitive projects. Utility scale systems are providing a majority of new capacity in some key markets such as **India**, the **USA**, **Spain** and **South Korea**, however most national markets were not led by this segment in 2022.

Merchant PV, where PV electricity is directly sold to electricity markets or corporate PPAs, (where it is directly sold to corporate consumers) is experiencing growth in numerous countries for the second year in a row, particularly in established markets where it is pulled by high electricity consumption prices, and is one of the key trends of 2022. As PV becomes more and more competitive, project developers are abandoning tender processes, leaving competitive tenders undersubscribed in some mature markets. Such development is mostly independent from financial incentives and therefore policy decisions, which makes its potential virtually unlimited.

However, whilst financial viability is no longer a problem in these cases, in reality limitations are already being seen due to grid congestion, social acceptance or strict environmental impact study requirements in others. Recent 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**, **Brazil**)

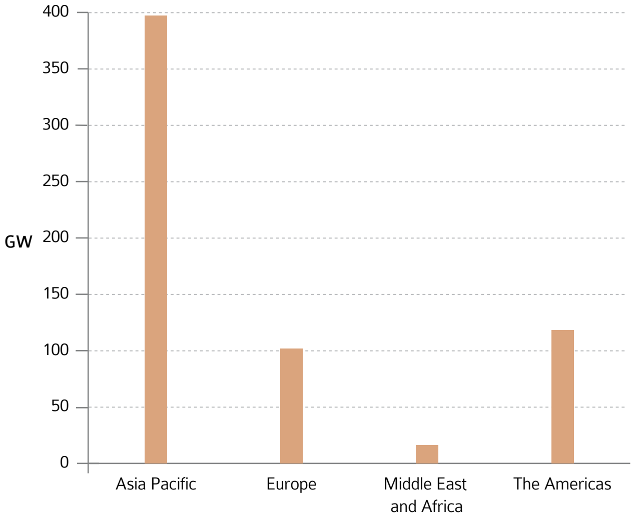
New utility-scale PV plants are increasingly using trackers to maximise production and in parallel, the use of bifacial PV modules is increasing relatively fast as well. Floating PV is becoming a significant segment. The addition of storage systems has also become a trend in some countries, either pushed by specific rules in tenders or by attractive conditions for grid services and wholesale markets (**Australia**, **USA**). In 2022, utility-scale plants amounted to 120 GW globally and the total installed capacity for all of these applications amounted to 648 GW; or 55% of the cumulative installed capacity.

**FIGURE 2.11**: CENTRALISED PV INSTALLED CAPACITY PER REGION 2022



SOURCE IEA PVPS & OTHERS

**FIGURE 2.12**: CENTRALISED PV CUMULATIVE INSTALLED CAPACITY PER REGION 2022



SOURCE IEA PVPS & OTHERS

## PROSUMERS, POWERING THE DISTRIBUTED PV MARKET

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 important as it can remove pressure on financial incentives and, in parallel, reduce demand on grid capacity.

Historically driven by simple schemes such as net-metering, prosumer segments are increasingly developed around the concept of self-consumption, where a distinction is made between the electricity consumed on site and the electricity injected into the grid on a close to real-time timestep, thereby incentivizing self-consumption.

An important factor in the success of self-consumption schemes is the retail electricity price, that is still being maintained artificially low in some countries. Subsidies for fossil fuels are still a reality and reduce the attractiveness of solar PV installations, across all market segments including self-consumption. However, PV markets tend to grow quickly when electricity prices increase, and overall, there is a clear trend toward self-consumption of PV electricity in most countries, often with regulations offering a value for the excess electricity, either through government mechanisms or utility schemes. This can be done with a FiT, a feed-in-premium added to the spot market price or more complex net-billing including time-of-use rates. Unfortunately, the move towards pure self-consumption schemes can create temporary market slowdowns, especially if the transition is abrupt, as consumers and market players adapt their understanding. However, if the market conditions are favourable and the market regains confidence, self-consumption can become a market driver for the distributed segment. Countries where the distributed segment is driving overall market growth include **Germany**, **Brazil**, **Poland**, **Sweden** and **Australia**.

**TABLE 2.4**: TOP 10 COUNTRIES FOR DISTRIBUTED PV INSTALLED IN 2022

| COUNTRY | GW |
|---|---|
| CHINA | 51.11 |
| USA | 8.63 |
| BRAZIL | 7.33 |
| GERMANY | 4.27 |
| INDIA | 4.19 |
| POLAND | 3.63 |
| SPAIN | 2.99 |
| JAPAN | 2.90 |
| AUSTRALIA | 2.83 |
| ITALY | 2.02 |

SOURCE IEA PVPS

**TABLE 2.5**: TOP 10 COUNTRIES FOR CUMULATIVE DISTRIBUTED PV INSTALLED CAPACITY IN 2022

| COUNTRY | GW |
|---|---|
| CHINA | 159.33 |
| GERMANY | 53.56 |
| USA | 51.63 |
| JAPAN | 51.01 |
| AUSTRALIA | 19.59 |
| ITALY | 16.57 |
| BRAZIL | 16.41 |
| INDIA | 12.30 |
| VIETNAM | 10.51 |
| TÜRKIYE | 10.28 |

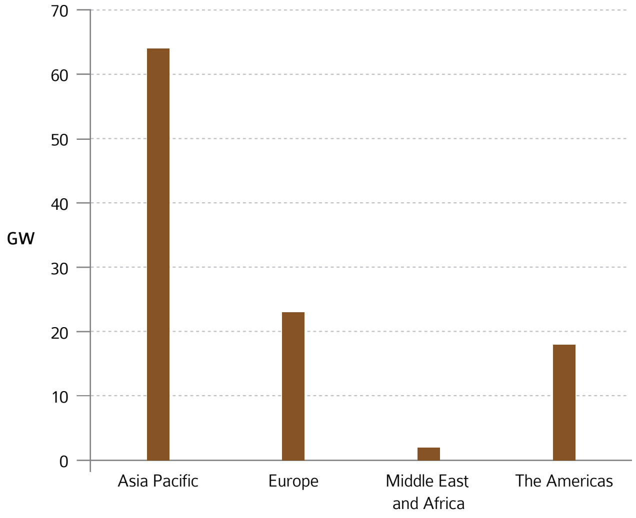
SOURCE IEA PVPS

## PV MARKET SEGMENTS / CONTINUED

The distributed market has been oscillating between 16-19 GW from 2011 to 2016, until **China** succeeded in developing its own distributed market: it allowed the distributed PV market to grow significantly by roughly doubling over several years from 2016 to 2018. In 2022, worldwide this market grew to 115 GW, up from 80 GW in 2021.

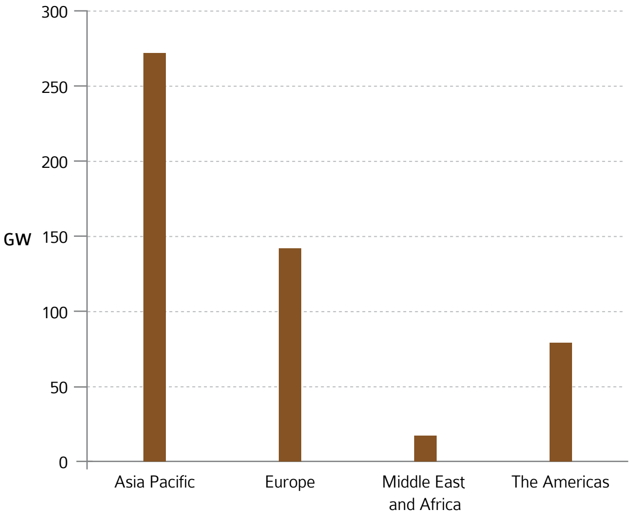
Several countries promote collective and distributed self-consumption as a new model for residential and commercial electricity customers. This model allows different consumers located in the same building or private area (collective self-consumption), or in the same geographical area requiring use of the public grid (distributed or virtual or delocalized self-consumption), to share the self-generated electricity, thereby unlocking access to self-consumption for a wider range of consumers. Such regulation, if well implemented, will allow the development of new business models for prosumers, creating jobs and local added value while reducing the price of electricity for consumers and energy communities. These models of production could also positively impact grid integration of PV systems by enhancing the adequation of production and demand. In the case of virtual (or distributed) self-consumption, the prosumers are not grouped behind a meter. We will call virtual (or distributed or delocalized) self-consumption, the case where production and consumption can be compensated at a certain distance, while paying a fair share to cover grid costs.

**FIGURE 2.13**: DISTRIBUTED PV INSTALLED CAPACITY PER REGION 2022



**SOURCE** IEA PVPS & OTHERS

**FIGURE 2.14**: DISTRIBUTED PV CUMULATIVE INSTALLED CAPACITY PER REGION 2022



**SOURCE** IEA PVPS & OTHERS

## DUAL USAGE AND EMERGING PV MARKET SEGMENTS

The installation of solar PV installations on infrastructure or land used for other purpose is a response to the competition for land that will result from the development of new PV capacities, and social acceptance problems. Social acceptance and surface availability will be key elements in the massive deployment of new PV capacity in a certain number of countries, typically where there is existing or spreading urbanisation, loss of agricultural land or strong preservation of heritage buildings and natural landscapes for aesthetic reasons.

For ground-mounted installations, competition has arisen between other uses and electricity production, dominated by conflict on agricultural land. By proposing a combined use for both agricultural production and energy production, agrivoltaics offers an acceptable alternative. Floating solar photovoltaics is a particularly dynamic market segment in Asian regions where the tension on land is strong, using the available surfaces on natural and artificial lakes and reservoirs.

These market trends in the centralised segment are strong and underpinned by the same imperative of 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 conflict.

On a smaller individual scale, integrating PV into and onto buildings has been a target for specialised companies for a long time – and has even been the mainstay of public policies for the distributed segment in the past in some countries (most notably **France**). It can be attractive because it uses existing buildings and also can lead to a more harmonious integration in the environment, reducing social resistance.

### AGRIVOLTAICS: NEW FRAMEWORKS AND DEVELOPING INTEREST

The development of PV on agricultural land existed since the early days of utility-scale PV. In some cases, this means crops have been replaced by photovoltaics and land use shifted towards electricity production. Agrivoltaics, however, proposes a different approach with the possibility to use land for both food and energy production. 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. Dual use of land is an option being thoroughly investigated around the world to address this topic.

The potential for PV on agricultural land and how this segment can contribute to achieving renewable energy targets has been studied in some 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 relative weight of this segment, in **Japan** a mapping of all agricultural land suitable for PV concluded that just 10% could hold 440 GW of PV – it can be noted that in 2022 for all segments in **Japan** cumulative installed capacity is "only" 85 GW. **South Korea**'s perspective of agrivoltaics development is 10 GW in 2030, which is half of the cumulative installed capacity at the end of 2021 (21.5 GW). Covering just 1% of the European Union's agricultural lands could allow the installation of 410 GW – but just 10% of this was installed in 2022 (39.5 GW) in the European Union and the top target of the RePowerEu plan is set at 750 GW in 2030.

In most countries PV in agricultural land is implemented with different configurations and designs and sometimes specific vocabularies:

- PV systems above crops or plants. The system is adapted to growing different kinds of crops with reduced solar irradiation, and could provide new services and business models – such as protection against hazards that damage crops (hail, excessive sun), water saving (though reduced evaporation) - or environments adapted to crops that would not have been possible in the actual or future climate conditions. This dual use imposes a specific design of PV systems. One of the technical solutions implemented is mobile elevated PV plants, where PV panels can in some cases change their position (tilt) to maximize PV production or maximize crop production depending on weather conditions. Elevated PV has also been implemented without tracking where the density of PV is adapted to the crops needs. 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 animal husbandry can be hosted between the rows of PV plants. The systems must enable the land to maintain its agricultural vocation. The design of the PV plant must be adapted to the activity: adequate space between the rows to allow agricultural machinery, the 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 the potential for PV on agricultural lands is important, 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 evaluations, social acceptance and water management also important factors. Following pioneer countries such as **Japan**, where "solar sharing" has been defined since 2003 and refers to PV installation allowed where 80% of agricultural yields are maintained and the guideline was published in 2021 and updated in 2023, **France**, **Germany** and **Italy** also have published frameworks or guidelines in 2022. **Italy** announced a major funding package for 2 GW and published the requirements for obtaining planning permissions and a dedicated support system. They distinguish two types of systems: "Agrivoltaic" systems that can, at a minimum, ensure interaction between energy production and agricultural production; and "Advanced Agrivoltaic systems", which are also eligible for incentives. DIN SPEC 91434, the German Standard for agrivoltaics was published and shapes the German framework and support scheme. Criteria are based on agricultural yield (at least 66% of the reference yield) and the agricultural use of the land must be guaranteed.

# DUAL USAGE AND EMERGING PV MARKET SEGMENTS / CONTINUED

"Interval" and "overhead systems" are differentiated in the definition, as are the expected outcomes and the support. In **France**, in 2023 agrivoltaics has been defined in the new Law for the Acceleration of Renewables where an agrivoltaic installation is considered to be an installation which directly contributes to agricultural activities: improving agronomic potential, protection against hazards, improving animal welfare and guaranteeing significant agricultural production.

System costs and profitability 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.

To summarise, in the different frameworks and support mechanisms, the two main types of projects are:

- PV plants where agricultural production is maintained. These systems are economically viable and cost-effective. Energy production dominates but agricultural production must be maintained. These projects participate in the classic competitive tenders or negotiate PPAs.
- PV plants complying with advanced criteria and where the PV systems are also enhancing agricultural production and farmer revenue, where stricter definitions have been made. Agricultural production profitability must dominate, and energy production is an added value. This type of plant can in many cases receive higher incentives than just the sale of electricity.

For now, agrivoltaics is still an emerging market when compared to global PV capacity. **Japan** has seen more than 1 800 agrivoltaic farms commissioned, but most of them are small systems. Between 2013 and 2021, less than 1 GW was installed. **China** has also an important installed capacity but this segment doesn't appear to be monitored separately. **Italy** announced a major funding package support for 2 GW, including agrivoltaics on roofs in rural areas. Specific calls for tender have been set for agrivoltaics in numerous countries including **Israel** with a tender for 100 MW of agrivoltaic systems in 2022.

## IIPV: INFRASTRUCTURE INTEGRATED PV

The potential of areas, sites and structures close to mobility infrastructures (railways, roads, etc.) and the surfaces of linear water bodies (irrigation canals, river banks, lakes, lagoon) could partly address the problems of socially acceptable land use for PV.

Unused land along roads, highways and railways have a significant potential for ground-mounted PV plants. 150 MW have been installed in **South Korea**, with more projects in the **USA** and the **Netherlands**. Integrated PV on roads (cycle ways, railway, or roads) have been trialled in the past years (**France**) with varying degrees of success.

PV vertical walls along roads, highways, railways with or without sound barriers have historically been developed in Europe (**Switzerland**, **Germany**, **Austria**, **Netherlands**) and there is continued and growing interest.

PV shade canopies on irrigation canals, developed in **India** since the 2010s in projects of several MW, are starting to spread elsewhere, mainly in regions subject to high evaporation rates of irrigation water. Several elevated PV systems over cycleways and roads are being tested, as are projects on dikes (the **Netherlands**).

## FLOATING PV: CONTINUED GROWTH

In densely populated areas the proximity of water bodies to load centres is often an advantage. Traditional land-based solar systems face either competing uses 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. Floating PV 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 (over 1.3 GW for about 30 projects).

The installed capacity of FPV systems worldwide surpassed 3 GW in 2021, with further growth in 2022 (up to 5.6 GW cumulative capacity depending on sources). Most of the growth in 2022 was in Asia-Pacific as in previous years, with large scale projects (over 50 MW) commissioned in 2022 in **India** (Kerala, Rajasthan) and **China** (Shandong), whilst commissioned projects were on a smaller scale in Europe (**France**, **Portugal**, the **Netherlands**), and MENA (**Tunisia**).

Project development remained dynamic, with new contracts for increasingly larger projects signed in **India** after a specific tenders round; additionally, aggressive development targets have been set by development companies for the creation of strong localised portfolios of FPV in **India** (1 GW in Assam), **Philippines** (1 GW) or even Zimbabwe (1 GW), whilst local governments and utilities are increasingly incorporating the development of FPV into generation and climate action roadmaps (**Germany**, **Spain**, **Portugal**, **India**). Specific tenders have been run in some countries (**India**, **Portugal**). Of note, the winning bid in **Portugal** was for a project with a negative requested Contract for Difference price per kWh – the profitability of generated electricity market sales such that it plans to generate revenue for subsidy mechanisms.

Floating PV has gained an early foothold on subsidence areas of former (coal) mines and quarries filled with ground water, unsuitable for industrial or agricultural activities and generally with little bioactivities (leading to minimal environmental impacts). Installing FPV on hydropower dams has advantages (for example when conjointly operating the solar and hydro power generation, rather than pure colocation of the FPV plant on the reservoir). Apart from the diurnal cycle (i.e., generating solar power during the day and saving water for hydropower generation at night), there is also a possible seasonal benefit in areas with dry and wet seasons. Depending on the turbines and their reaction times, it is also possible to buffer some of the short-term variability from solar (due to cloud movements) and use the reservoirs as a "giant battery". Planned floating PV projects on hydropower reservoirs often aim for large capacities such as in **Thailand** (3.5 GW), **South Korea** (2.1 GW), **Laos** (1.2 GW) and **Zimbabwe** (1 GW).

The challenges of near-shore and off-shore marine FPV projects are the more demanding environments, where tidal currents, richer marine life, wind, waves and the presence of salt water all need to be considered. The potential for near-shore areas is significant as unused space can be activated for energy harvesting close to load centres in coastal settlements and harbours. Going further off-shore aggravates the challenges and cost but still has possible applications, especially for powering oil and gas platforms or for using the existing transmission infrastructure and vast ocean spaces between the towers in off-shore wind farms (0,5 MW system commissioned in **China** in 2022 and testbeds in the **Netherlands** and **Belgium**).

Most of the installations in operation use HDPE plastic floats, (Ciel & Terre and Sungrow together have a significant market share) but there are an increasing number of different designs, ranging from a combination of floats and metal structures (e.g. Zimmermann) to membranes that are held in place by large plastic rings (e.g. Ocean Sun). For off-shore applications, more robust designs are being test-bedded, for example by Oceans of Energy or SolarDuck.

Going beyond floating solar, the use of near-shore pile based fixed systems to take advantage of unoccupied space is also being explored, for example with the ambitious goal of 11.25 GW in Shandong Province (**China**) spread across 10 plants.

Experts expect cumulative capacity of over 60 GW by 2030, led by **China**, **India**, **Indonesia** and **South Korea**, as the currently most dynamic market in Europe (the **Netherlands**) reaches saturation, whilst different studies have evaluated regional potentials – the JRC estimating that on the largest reservoirs of Africa the potential was nearly 3 000 GW[3] whilst other studies indicate a global potential of up to 4 TW.

## BIPV: A RAPIDLY GROWING NICHE

Market perspectives for BIPV are positive, as past obstacles are progressively overcome: products are technically mature, from modules to mounting systems, and awareness is rising in the construction sector and costs have been steadily decreasing. In many countries, there is new regulatory pressure to improve the energy performance of buildings and decarbonize their energy supply. However, much remains to be done to generalise BIPV. Education amongst professionals of the building construction sector is still too limited, and there is a real shortage of people combining PV and building related skills (across design, performance simulations, knowledge of existing solutions, constraints,).

BIPV will remain a niche of both the construction and PV sectors, as the competition is and will be fierce with other technical (traditional) solutions - but it could become a significant niche as it combines unique characteristics allowing it to fill gaps that other technical solutions cannot for a number of configurations, whilst responding to regulatory mandates for positive energy buildings.

The BIPV market is difficult to estimate. With multiple business models, different incentives, many kinds of buildings and infrastructures (including roads), from tiles and shingles for residential roofs to glass curtain walls and more exotic façade elements in case of commercial buildings, BIPV covers different segments with a large variety of technical solutions. Depending on the definition considered, the BIPV market ranged from 300 MW to 500 MW per year in **Europe** last year and probably reached 2 GW globally. Indeed, the differences between custom-made elements and traditional glass-glass modules can be difficult to assess. Simplified BIPV, using conventional PV modules with dedicated mounting structures, is still leading the BIPV market. The market is also split between some industrial products such as prefabricated tiles (found in the **USA** and multiple European countries for instance), to custom-made architectural products fabricated on demand. Finally, while the supply has been "Western-centred" for a long time, in **China** many manufacturers are adding BIPV products to their catalogue, including mainstream manufacturers.

## 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 are developing more rapidly than in the past, mainly thanks to rural electrification programs essentially in Asia and Africa but also in Latin America.

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[3] https://www.sciencedirect.com/science/article/pii/S0960148121000471?dgcid=rss_sd_all

## DUAL USAGE AND EMERGING PV MARKET SEGMENTS / CONTINUED

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 network. 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 (production) business. Batteries are also used to extend the duration of energy use.

This trend is specific to countries that have enough solar resources throughout the year to make a PV system viable. In such countries, PV has been deployed to power off-grid cities and villages or for agricultural purposes such as water pumping installations. Supplying electricity to remote mining operations and communities is also growing, fro example in Australia.

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.

PV increasingly 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 expected to leapfrog complex and costly grid infrastructure, especially to reach the “last miles”. The challenge of providing electricity for lighting and communication, including access to the internet, will see the progress of PV as one of the most reliable and promising sources of electricity in developing countries in the coming years. Specific business models are developed in Africa for instance and large energy groups such as Engie Energy access for instance are targeting millions of people with such products.

In most developed countries in Europe, Asia or the Americas, there is little need for these systems, and the future development of off-grid applications will most probably only be seen on remote islands.

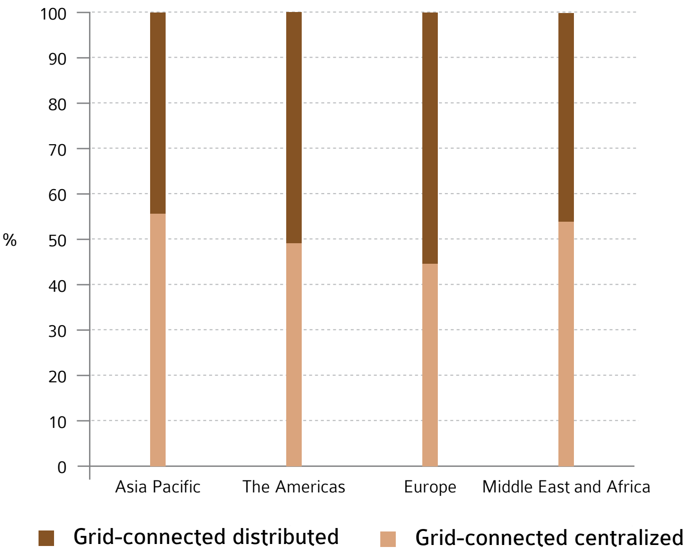
## PV DEVELOPMENT PER REGION

The early years of PV development started with the introduction of incentives in Europe, particularly in **Germany**, and caused a 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 and 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 is quite visible and still true today, with the share of the Asia-Pacific region stabilizing around 60% in 2022. Since then, Asia continues to lead PV development, with the other regions following.

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 2.15**: ANNUAL GRID-CONNECTED CENTRALISED AND DISTRIBUTED PV INSTALLATIONS BY REGION IN 2022



**SOURCE** IEA PVPS & OTHERS

## THE AMERICAS

The Americas represented 35 GW of installations and a total cumulative capacity of 192 GW in 2022. Whilst most of these capacities are installed in the **USA** and **Brazil**, several countries have cumulative capacity over the GW level and continue to install several hundred MW per year (**Canada**, **Mexico**).

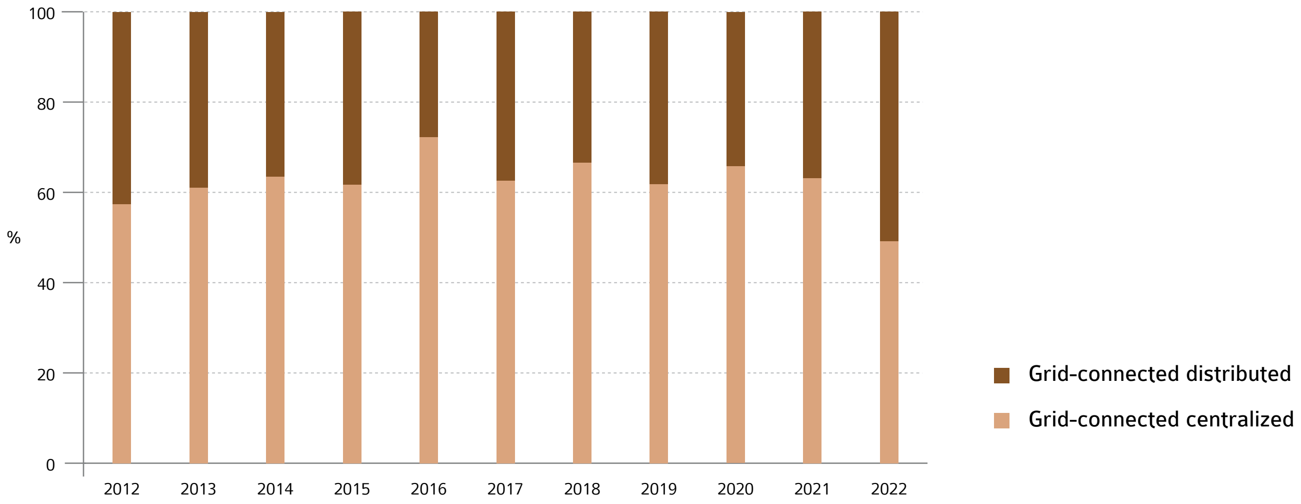
PV is developing in the Americas both in the distributed and centralised segments; the **USA** is pulled by the utility scale segment, as is the market in **Canada**, running both on tenders and PPAs, whilst conversely, **Brazil** and **Mexico** are led by the distributed segment. However, the **USA** also saw record growth in the distributed sector as well, installing nearly 6 GW of residential systems and over 1 GW of community solar projects.

Instability has characterized the development of PV in most American countries in the last years, with stop-and-go policies in the **USA**, **Canada**, **Honduras** or **Mexico** for instance. The market was dynamic in 2022 in **Brazil**, **Chile** and **Mexico** with prospects for development in several central American countries, such as **Costa Rica**, **Guatemala** and more.

Outside of the IEA PVPS membership, **Brazil** remains the most important market in the Americas: it added 9.9 GW in 2022 for 23.6 GW of cumulative PV installed capacity with most of the newly installed capacity coming from distributed generation. PV installations in **Chile** grew in 2022 by 1.8 GW reaching a cumulative installed capacity of 7.9 GW, with residential systems nearly doubling in number, and in a country first, a reverse auction was launched by a private solar generator to sell 380 GWh annually of electricity to utilities and wholesalers. In 2023, the **Chile**an market is facing grid congestion that could slow growth. **Canada** added 765 MW (down from a record 2 GW in 2021) to reach 6.5 GW cumulative capacity whilst **Mexico** added just 680 MW, its lowest annual market since 2017.

In other countries, 2022 was an uneven year - in **Argentina**, development continues, with around 1.2 GW cumulative installed capacity in the country at the end of 2022 and 200 MW installed in 2022; different programs have been run to equipe hundreds of public buildings with solar and the launch of a project for 500 MW on two sites. In **Peru**, over 2 GW of projects had their environmental studies approved, concessions for several hundred MW were given, with a planned 600 MW of solar to be commissioned in 2023. **Ecuador** launched an oversubscribed tender for 120 MW, and in **Columbia** works started on 480 MW. **Cuba** may increase capacity in the coming years as a procurement tender was opened for 900 MW combined of solar across nearly 200 sites.

**FIGURE 2.16**: EVOLUTION OF PV INSTALLATIONS IN THE AMERICAS PER SEGMENT



SOURCE IEA PVPS & OTHERS

# PV DEVELOPMENT PER REGION / CONTINUED

## ASIA-PACIFIC

The Asia-Pacific region installed 143 GW in 2022 and the total installed capacity reached 677 GW. The market was dynamic in all parts of Asia, and significant growth was recorded. In 2022, the region represented 60% of global PV installations, on the back of the strong performance of markets in **China**, **India** and **Japan**. 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.

Asia is home to several IEA-PVPS GW-scale markets in 2022: **China**, **Japan** but also **Australia**, **South Korea**, and with lesser volumes **Malaysia**.

**China** installed 105.5 GW (revised since the publication of the IEA PVPS Snapshot) for a cumulative capacity of 414 GW. Market growth was evenly balanced across utility and distributed segments, with 51 GW of distributed capacity, roughly half of which was installed on residential buildings thanks in part to the national policy. 54 GW DC (36.3 GW AC) of centralised PV was installed across the country. Volumes were spread unevenly across the country, with the highest concentration in the provinces running down the coast from Beijing. Over 2022, there was significant growth in upstream manufacturing, with the impact on module prices seen from the end of the year (see Chapter 6).

Outside of the IEA-PVPS network, the largest market 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 continued in 2022 adding 18.1 GW. The Indian market is dominated by utility scale PV (over 75% of annual capacity) however despite over 25 GW of tenders including five tenders for 1 GW to 1.5 GW launched, some tenders were undersubscribed due to multiple factors including lower profit margins, rising project costs due to changes in taxes and eligible products, and investor wariness after some state distribution companies looked to renegotiate contracts.

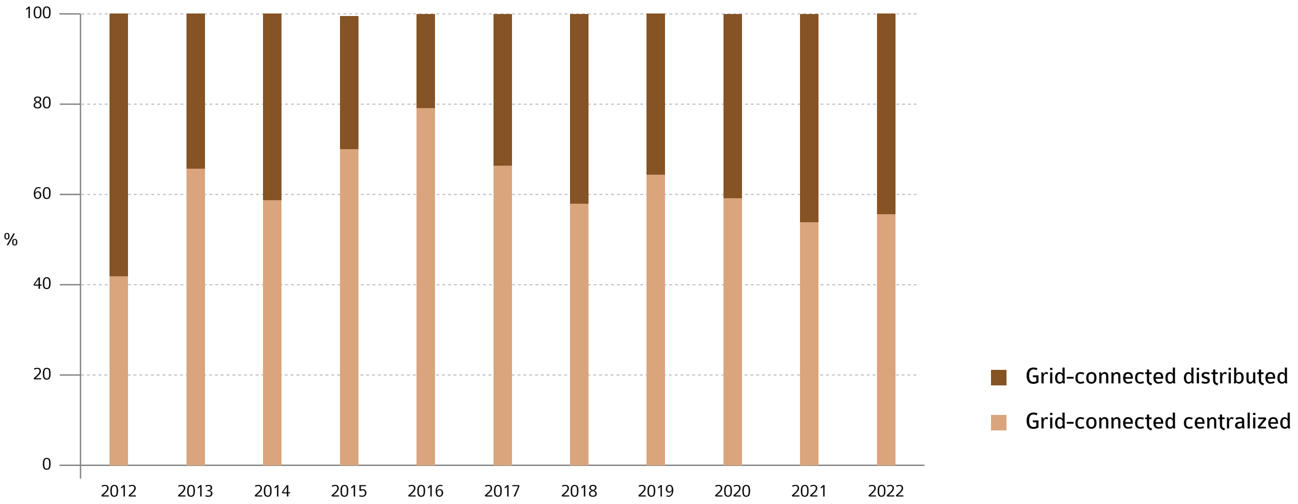
The market in **Japan** was steady at 6.7 GW, for a cumulative total of 85 GW, equally spread across the centralised and distributed segments. Both **South Korea** and **Australia** saw reduced markets in 2022 due to policy changes, supply issue and grid congestion, (3.1 GW and 4.2 GW new capacity respectively) with cumulative capacity of 24.3 GW and 30.3 GW. **Taiwan** remained dynamic and added 2 GW to reach 9.7 GW in total.

In Southeast Asia, **Malaysia** installed 1.1 GW of new capacity in 2022, bringing cumulative capacity to 3.6 GW as talks move forward to remove the ban on exporting renewable electricity, talks that could pave the way to participation in an ASEAN Power Grid. **Thailand** installed just 200 MW new capacity to reach 4.3 GW, with the first instalment of a floating PV coming on line for what will eventually be a 2.7 GW multisite plant. In **Vietnam**, new capacity was a low 100 MW, a far cry from the 5.2 GW installed in 2019 and down even on last year's 1.9 GW, however with a high penetration rate, grid congestion and stability are real challenges for the country. **Singapore** saw 160 MW of new capacity. The **Philippines** is expected to grow after 1.5 GW of projects was awarded in tenders in 2022, and a GW scale project for export to **Singapore** from **Indonesia** is in the planning stages.

**Bangladesh** saw new development with 290 MW (200 MW centralised) new capacity, in contrast to previous years where off grid was strongly developed. There is 960 MW cumulative capacity.

The market is growing slowly in several other countries, at a different speed, such as in **Pakistan**, where a tender for a few hundred MW was authorised.

**FIGURE 2.17**: EVOLUTION OF PV INSTALLATIONS IN ASIA PACIFIC PER SEGMENT



**SOURCE** IEA PVPS & OTHERS

## 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 strong 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. This was the case again in 2022. Europe (not just the European Union) saw its PV market growing again in 2022, with 41.5 GW installed, which accounted for 17.6% of the global PV market. European countries had close to 242 GW of cumulative PV capacity by the end of 2022, the second largest capacity globally. 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 Tariffs schemes to start developing PV, in the past few years there has been a movement to self-consumption (or variants) for distributed PV while tenders 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. Collective and delocalized self-consumption are slowly developing in several countries where regulatory frameworks are catching up to market demands[4]. BIPV has been incentivized more than in any other location 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**, and could lead to a significant market share in a near future, whilst the use of PPA and corporate PPAs continues to grow. In general, PV development in Europe continued to be dynamic over 2022 despite price hikes and some lingering supply chain issues, mostly resolved by the 4th quarter of 2022.

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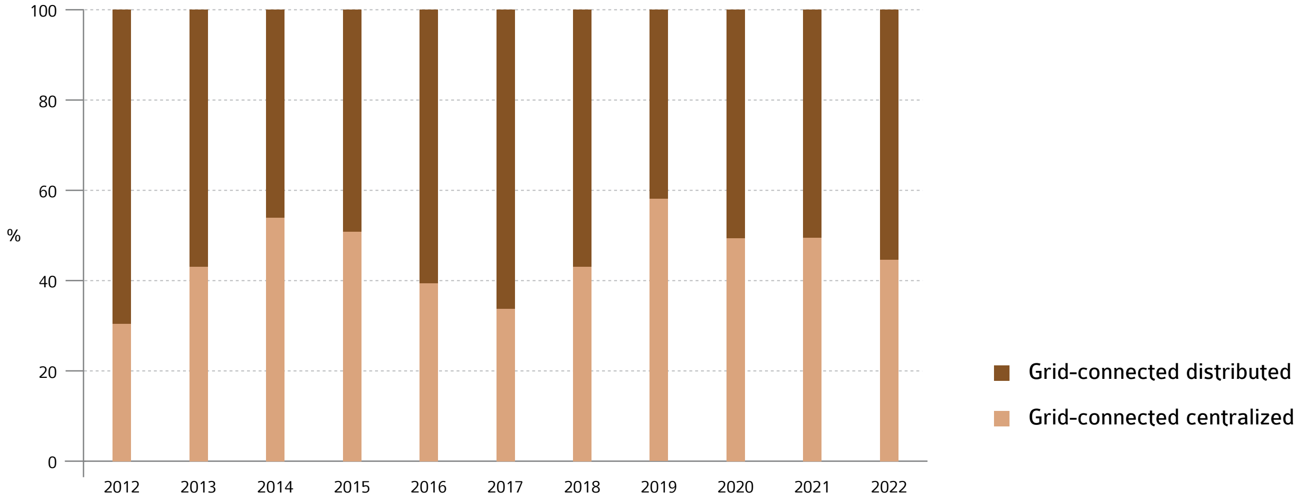
[4] See the IEA PVPS Task 14 paper "Self-consumption of electricity produced with photovoltaic systems in apartment buildings - Update of the situation in various IEA PVPS countries"

# PV DEVELOPMENT PER REGION / CONTINUED

**FIGURE 2.18:** EVOLUTION OF PV INSTALLATIONS IN EUROPE PER SEGMENT



**SOURCE** IEA PVPS & OTHERS

## EUROPEAN UNION

### Policy Framework

In December 2018, the revised European Renewable Energy Directive (RED II) set a 32% renewable energy target by 2030, up from a target of 20% in 2020[5]. In 2019 the European Green Deal was introduced, an action plan to boost the efficient use of resources by moving to a clean, circular economy and to restore biodiversity and reduce pollution. A pillar of the European Green Deal is a commitment to be climate neutral by 2050. In September 2020, the European Commission proposed raising the 2030 climate targets aiming at a 55% GHG reduction by 2030. The accompanying impact assessment[6] showed that such an increase in the climate ambition is realistic and economically feasible. The 55% GHG reduction target will require a share of renewable energy of approximately 38.5% according to the impact assessment.

In the European Union, solar energy and photovoltaics in particular were identified as one of the cornerstones of a rapid and more ambitious deployment of renewable energy technologies in order to meet the climate-neutrality objective in 2050 and a significant reduction of the EU's dependence on imported fossil fuels. Although the currently proposed measures include a strong component to diversify the source of fossil fuel imports away from Russia, a path on how to phase out entirely their use is not yet clear. The full implementation of the "Fit for 55" proposals would lower the Union's gas consumption by 30%, still requiring over 200 bcm, by 2030.

Each EU Member State had to prepare a national recovery and resilience plan, which outlines their individual reform and investment agendas for the years 2021-2023 in order to be eligible for the Recovery and Resilience Facility. A minimum of 37% of expenditure are earmarked for actions to combat climate change.

In March and May 2022, the European Commission published the REPowerEU Communication and the Solar Strategy Communication respectively[7,8]. REPowerEU aims to reduce net emissions by at least 55% by 2030 and the Solar Strategy called for an additional photovoltaic capacity of 450 GWp between 2021 and 2030, which would mean a roughly fourfold increase of the nominal capacity to over 720 GWp by 2030.

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[5] European Commission, REPowerEU Communication, 08.03.2022, COM(2022) 108 final

[6] European Commission, Solar Strategy Communication, 18.05.2022, COM(2022) 221 final

[7] European Commission, REPowerEU Communication, 08.03.2022, COM(2022) 108 final

[8] European Commission, Solar Strategy Communication, 18.05.2022, COM(2022) 221 final

The European Solar Communication includes a number of building blocks to accelerate the deployment of PV in a timely manner. The following initiatives are aimed to deliver the expected outcome:

- European Solar Rooftops Initiative
- Utility scale deployment including multi use of land (e.g. agrivoltaics, floating-PV, PV on noise barriers, etc.)
- Solar value for buildings, districts and cities
- Preparing the energy network for the efficient distribution of solar energy
- Establishment of a resilient supply chain
- Supporting investments regarding EU PV manufacturing (de-risking, funding)

The latest initiative is the proposal of a Net-Zero Industry Act [European Commission, Proposal for a Regulation Of The European Parliament And Of The Council on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act), 12.05.2023, COM (2023) 161 final.] to create a favourable environment to scale up manufacturing of net-zero industries in the EU. One of the identified strategic net-zero technologies is PV. A simplification of the regulatory framework (permitting) for PV manufacturing and support for skills development are among the actions included in the Act that will help increase the EU PV competitiveness.

### State of Play

At the end of 2022, the total installed PV power capacity in the European Union had surpassed 213 GW.

Almost 55% of this were residential and commercial rooftop installations. The PV market in the European Union was declining for six years before the trend reversed in 2018. During the first nine months of 2022, more than 70 GWp of modules were imported into the European Union, but due to shortages of inverters (chip shortage) and the labour market, the annual market for new PV installations grew just a little more than 33% to about 39 GW in 2022. Twelve countries installed more than 1GW, namely **Spain** (8.5 GW), **Germany** (7.2 GW), **Poland** (4.9 GW), the **Netherlands** (3.9 GW), **France** (3.0 GW), **Italy** (2.5 GW), **Denmark** (1.6 GW), **Greece** (1.4 GW), **Austria** (1.0 GW), and **Belgium** (1.0 GW).

The **Netherlands** are leading in terms of installed capacity per capita in the EU with 1031 Wp, second only to **Australia** with 1169 Wp. Six EU countries have more than the European Union average, namely, **Germany** (800 Wp), **Denmark** (580 Wp), **Malta** (535Wp), **Belgium** (698 Wp), **Greece** (602 Wp), and **Spain** (629 Wp). So far, only five countries have installed less than the world average of 148 Wp per capita. However, the EU average installed PV capacity per capita has increased by only 220 Wp between 2019 and 2022.

### Other European Countries

Outside of the IEA-PVPS network, **UK** installed just 555 MW in 2022, still far from the GW-scale market it used to be a few years ago. The country had more than 15 GW of PV at the end of the year 2022, with a market mostly focused on small-scale applications. PPA-driven utility-scale PV could develop in the coming years.

In the Russian Federation the "Energy Strategy of Russia for the Period Up to 2035" set a target share of renewable energy in total electricity production at 4.5% by 2024. Furthermore, the Russian government set a target of 25 GW for the installation of renewable electricity capacities towards 2030. In 2022 about 200 MW of new PV capacity was installed in **Russia**, increasing the total capacity to 2.2 GW (including 400 MW in Crimea).

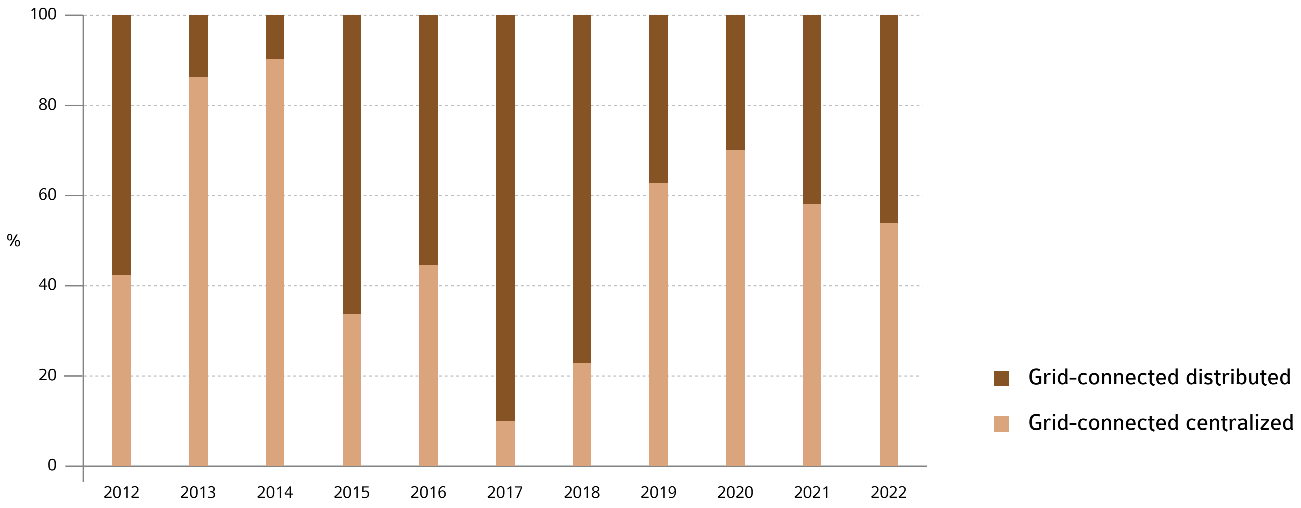
**Switzerland** has also installed more than 1 GW for the first time in 2022, with 1.1 GW, almost all in rooftop installations.

## MIDDLE EAST AND AFRICA

In MEA (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 year 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 2.19**: EVOLUTION OF PV INSTALLATIONS IN AFRICA AND THE MIDDLE EAST PER SEGMENT



SOURCE IEA PVPS & OTHERS

## MIDDLE EAST AND NORTH AFRICA

Over the past decade, many countries, especially in the Middle East have started to connect large-scale PV power plants and more are in the pipeline. 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. However, less than 4 GW was installed in the region in 2022, representing about 1.5% of the global market.

Often energy prices are supported by government spending, which limited the ability of PV to compete for years, however countries such as **Iran**, **Tunisia**, **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 conditions for distributed PV, with net-metering being proposed in some countries such as in **Egypt**, **Dubai** (UAE), **Bahrain**, **Jordan**, and FiT or other mechanisms in **Iran**, **Israel**, **Saudi Arabia**, **Tunisia**, with plans to introduce similar schemes in **Qatar**, **Morocco**. The **UAE** is facilitating the connection of distributed generation to the network to help relieve peak loads. **Türkiye** is looking to sustainable building mandates to promote distributed solar. Another trend in the fast-developing region is the willingness for government 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 or long term in the region, with government and state-owned organisations tendering for single site or multi-site projects as procurement exercises. Examples in 2022 include projects in **Bahrain** (72 MW multi-site) and **Saudi Arabia** (2.4 GW for several projects). This year **Morocco** awarded 333 MW in its Noor PV II tender launched in 2019, whilst **Israel** ran a pilot agrivoltaics tender for 100 MW. In 2022, open tenders include those in **Iran** (4 GW capacity for systems above 10 MW awarding construction permits and PPAs). Along with **Israel's** plans for agrivoltaics, floating solar is also garnering attention as water conservation is a pressing problem given the dry and desertic climate, with a first pilot project commissioned in 2022 in **Tunisia** and contracts awarded in past years in the **UAE**. Experts believe the plans for solar projects in the MENA region by 2030 is nearly 50 GW, with nearly half in **Morocco** and **Oman**. It remains to be seen how much of this will be able to reach sufficient maturity to be built.

In 2022, **Israel** installed just under 1.2 GW to reach 4.5 GW, followed by **Qatar** with 800 MW, **Morocco** installed 130 MW to reach a cumulative capacity of less than 1 GW.

Local manufacturing is present in **Algeria** (inauguration of a new factory with 180 MW capacity) whilst **Saudia Arabia** has 3 module assemblers and is opening a factory targeting the supply of tracking equipment for up to 8 GW a year, complementing its solar module manufacturing capacity (including a 1.2 GW factory in Tabuk).

## 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 micro and small-scale PV seem to be unreported to authorities. The annual PV market is slowly coming back to its previous volume after having suffered through the impacts of COVID, food and energy crises, growing to an estimated 1.3 GW, just above 1% of global capacity but far below the estimated potential of the market. This is up from 2021's 1 GW but well below the 2018 volume of 3 GW. 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.

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 H2 can be reached.

The question of African power infrastructure and markets is essential since many countries have a small, centralised 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, but 2022 was not a growth year, with a regression of 18% year - on - year in terms of installed capacity. 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 such as the most competitive segment for the development of solar in Africa, especially in remote areas, - PV plants to replace or complement existing diesel generators. Many plants are expected to come online in 2023, as solar is already the cheapest source of new electricity across much of the continent and should outcompetes all sources continent-wide by 2030.

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 leverage financing difficulties for residential consumers, different pricing formats exist to foster access to clean and reliable electricity. Off-grid PV applications, such as water pumping installations, are expected to play a growing role in bringing affordable power to consumers.

Support policies and facilitating regulation is more than ever necessary to accelerate uptake ahead of the expected increase in energy consumption and electricity access. 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...

Most of the cumulative capacity installed on the African continent is in Southern Africa, with 52% followed by Northern Africa with 25%. Total cumulative capacity is led by **South Africa** (over 50% of capacity), followed by, **Kenya** (**Angola**, **Senegal**, **Mali**). In 2022, 284 MW was installed in just two large scale systems in **Angola**, with between 100 MW and 200 MW installed in **Mali** and **South Africa**, and over 70 MW installed in **Kenya** and **Ghana**.

In several countries, the question of local manufacturing is essential even if not yet visible in current policies. The willingness to manufacture locally and develop a manufacturing industry is present and will influence PV deployment in the coming years, for example in **South Africa**.

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. In sum, Africa can benefit from the global progress in technologies and cost reductions to leapfrog fossil fuel-based systems in the coming years areas - the potential for PV is still largely untapped.

# PV DEVELOPMENT PER REGION / CONTINUED

## **TABLE 2.6:** 2022 PV MARKET STATISTICS IN DETAIL

| COUNTRY | 2022 ANNUAL CAPACITY (MW) | | | 2022 CUMULATIVE CAPACITY (MW) | | |
|---|---|---|---|---|---|---|
| | DISTRIBUTED | CENTRALISED | TOTAL | DISTRIBUTED | CENTRALISED | TOTAL |
| AUSTRALIA | 2 863 | 1 377 | 4 239 | 19 984 | 10 385 | **30 368** |
| AUSTRIA | 858 | 151 | 1 009 | 3 537 | 255 | **3 792** |
| CANADA | 253 | 512 | 765 | 2 238 | 4 279 | **6 517** |
| CHILE | 820 | 939 | 1 759 | 2 143 | 5 781 | **7 924** |
| CHINA | 51 110 | 54 435 | 105 545 | 159 690 | 254 375 | **414 065** |
| DENMARK | 893 | 680 | 1 573 | 1 710 | 1 713 | **3 423** |
| FINLAND | 245 | 29 | 274 | 657 | 34 | **691** |
| FRANCE | 1 380 | 1 586 | 2 966 | 10 114 | 9 589 | **19 703** |
| GERMANY | 4 269 | 2 924 | 7 193 | 53 559 | 13 741 | **67 301** |
| ISRAEL | 703 | 455 | 1 158 | 2 642 | 1 865 | **4 507** |
| ITALY | 2 022 | 448 | 2 470 | 16 568 | 8 496 | **25 064** |
| JAPAN | 2 897 | 3 756 | 6 653 | 51 189 | 33 877 | **85 066** |
| SOUTH KOREA | 300 | 2 814 | 3 114 | 3 161 | 21 152 | **24 313** |
| MALAYSIA | 427 | 641 | 1 068 | 1 304 | 2 307 | **3 611** |
| MEXICO | 442 | 238 | 680 | 2 482 | 6 397 | **8 879** |
| MOROCCO | - | - | 130 | - | - | **829** |
| NETHERLANDS | 1 638 | 2 262 | 3 900 | 7 499 | 10 750 | **18 249** |
| NORWAY | 153 | 0 | 153 | 354 | 0 | **354** |
| PORTUGAL | 178 | 712 | 890 | 747 | 1 791 | **2 537** |
| SOUTH AFRICA | 56 | 56 | 112 | 1 114 | 3 628 | **4 742** |
| SPAIN | 3 008 | 5 452 | 8 460 | 6 299 | 23 675 | **29 974** |
| SWEDEN | 808 | 42 | 850 | 2 306 | 150 | **2 457** |
| SWITZERLAND | 1 084 | 0 | 1 084 | 4 515 | 226 | **4 740** |
| THAILAND | 100 | 100 | 200 | 1 000 | 3 278 | **4 278** |
| TÜRKIYE | 547 | 1 062 | 1 610 | 10 282 | 2 244 | **12 526** |
| UNITED STATES | 8 625 | 12 502 | 21 127 | 51 627 | 89 929 | **141 556** |
| IEA PVPS | 85 679 | 93 173 | 178 982 | 416 396 | 510 243 | **927 466** |
| BRAZIL | 7 332 | 2 519 | 9 851 | 16 408 | 7 151 | **23 559** |
| INDIA | 4 185 | 13 950 | 18 135 | 12 299 | 66 848 | **79 147** |
| NON-IEA PVPS | 27 191 | 29 785 | 56 846 | 110 096 | 146 711 | **255 979** |
| TOTAL | **112 869** | **122 959** | **235 828** | **526 491** | **656 954** | **1 183 445** |

SOURCE IEA PVPS & OTHERS

# three

## POLICY FRAMEWORK

The past year has demonstrated that despite PV competitivity, national markets remain sensitive to policy, with different segments responding to policy changes as they become effective. From the late 90's onwards, the development of PV was pushed by a variety of support mechanisms – from feed-in tariffs, direct subsidies, and tax credits to competitive calls for tender and feed in premiums. The initial goal was generally to compensate the lack of competitivity by reducing the gap between the cost of electricity from PV and the cost of electricity from conventional sources. More recently, the rapid reduction in PV costs has meant that competitivity is no longer a problem in a number of countries and across different segments (for more detail, see Chapter 6, competitiveness of PV electricity).

Predefined feed-in-tariffs that support centralised PV are being replaced in many countries by auctions with calls for tenders to propose the most competitive PV electricity. Tenders can be adapted, using the same auction process but awarding a variable premium, given on top of the wholesale market price where the electricity is sold. In a growing number of markets, tenders are awarding Contract for Difference (CfD) contracts, guaranteeing fixed remuneration levels for projects whilst funnelling profits from high electricity market costs back to government. When PV is so competitive that no financial incentives are required, large scale systems are moving to direct long-term private contracts between PV plant owners and off-takers for the electricity produced (PPAs), or the sale of electricity on wholesale markets (merchant PV). This has left tenders undersubscribed in some countries as developers turn to the market for higher revenue in a context of high electricity prices from the impacts of the Ukraine war. In these markets self-consumption is becoming the model of choice in residential and commercial markets with regulations and support measure being adapted.

Whilst in some competitive markets support mechanism have been stopped or adapted, to encourage emerginimperatives, the search for energy sovereignty and ambitious PV development goals mean that other countries are stepping up to accelerate deployment by increasing support budgets or support levels. 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, support schemes are evolving according to market maturity and investor confidence. Therefore, targeted financial incentives might still be needed for some years to overcome costs or investment barriers in specific countries.

In new markets, support for distributed PV markets often begins by setting feed-in tariffs, with a trend leaning towards lower or feed in tariffs being replaced by other mechanisms. In places where self-consumption is incentivized, initial support by net-metering mechanisms is moving to net-billing mechanisms, premiums or FiT tariffs for the excess electricity fed into the grid. 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.

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. The electrification of usages such as the transportation sector is an important factor in the energy transition, and EV sales are increasing rapidly, although it is difficult to establish direct correlation between EV and solar market growth. In parallel, development of "green" hydrogen projects powered by solar electricity continues stronger than before as the fragility of gas supply pushes governments to accelerate support.

Even if electricity procurement can be compensated by PV production, taxes and the financing of distribution and transmission grids are still animating the debate, shaping the regulatory framework and impacting business models and the price for PV electricity to compete.

With the share of PV electricity growing in the electricity systems of several countries, the question of integration to the electricity grid is becoming more acute. Simplification of inadequate and costly administrative barriers and streamlining of permit procedures is also a driver and progress has been noted in most countries in the last years. See Chapter 7 for more on grid integration.

## PV MARKET DRIVERS AND SUPPORT SCHEMES

The question of market drivers is a complex one since the market is always driven by a combination of context, regulations and incentives.

### ACCESS TO SUPPORT MECHANISMS AND REMUNERATION MODELS.

Access to support mechanism 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), 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.

### FEED-IN TARIFFS AND PREMIUMS IN OPEN ACCES SCHEMES

Predefined feed-in tariffs remain an important tool for ensuring the roll out of PV in the distributed segment, and many existing schemes continued through 2022. The trend is for new or annual FiT to be lower, matching the continued drop in PV costs across the distributed segment, although a few countries have slowed or halted decreases to compensate for the increased investment costs across 2021/2022 (**France**, **Germany**).

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 de 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. 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 members many countries had a FiT scheme in 2022, in most cases to support the residential market (**Australia**, **Canada**, **China**, **France**, **Germany**, **Japan**, **Portugal**, **Switzerland**, **Thailand**), sometimes extending to the commercial and industrial segments (**France**, **Germany**, **Italy**, **Japan**). With increased competitivity, a few countries are phasing out government based FiT schemes (**Australia**), whilst others are reinforcing them in line with more ambitious development targets (**Germany**). In many countries (**France**, some states in the **USA**), feed in tariff levels have been adjusted over 2022 to take into account the changing profitability of PV, given the increase in both electricity prices and PV costs.

The increase in electricity consumption prices has reduced the attractiveness of FiT in some countries compared to self-consumption and may lead to increasing number of countries either dropping FiT or reserving them for excess injections after self-consumption. Depending on the country specifics, FiT can be defined at the national level and at the regional, county or city level (**Australia**, **Canada**, **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**, **Switzerland**, **China (Hong Kong)**, outside of the policy framework to increase customer fidelity.

Feed in premiums (FiP) are premiums paid on top of the wholesale electricity market price. Fixed and variable premiums can be considered. **Sweden** and **Austria** are using a fixed FiP for small distributed systems.

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 learnt 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 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. In **Germany**, the level of the FiT can be adapted monthly to reduce the profitability of PV investments if the market is growing faster than the target decided by the government. In **Belgium**, there is a periodic re-evaluation of coefficients used to determine the value of green certificates in Brussels and Wallonia. In **France**, the FiT decrease is dependent on both installation rates and on economic indicators. The economic indicators and government intervention also allows for increased FiT if economic conditions (such as cost increases) require it - both **Germany** and **France** took advantage of their systems to halt drops or increase feed in tariffs in 2022, responding to both increased costs or more ambitious PV targets after being confronted with security of supply problems triggered by the war in **Ukraine**.

**FiT remains the most popular support scheme for grid-tied PV systems, especially for small household rooftops applications. The ease of implementation continues to make it the most used regulatory framework for PV globally, despite a trend to facilitated self-consumption, with or without incentives.**

## COMPETITIVE TENDERS

Competitive tenders have been increasingly used to stimulate and regulate medium to large scale systems across the world, either tendering access to support mechanisms, land or electricity procurement contracts. Traditionally they have been used to give access to government direct support in the form of feed in tariffs or premiums, more recently contract for differences, but increasingly utilities and governments are using them to secure procurement for electricity or generation capacity. They are also used to stimulate investment in specific types of systems, for example floating PV or, more commonly, 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".

In **Germany**, **Italy** and the **Netherlands**, the remuneration of solar electricity is based on a variable Feed-in Premium (FiP) that is paid on top of the average electricity wholesale market price for utility-scale systems. A Contract for Difference scheme (**UK**, **Greece**, **Poland**, **France**, and more recently **Italy**, **Hungary**, **Australia** and **Spain**) is a FiP that ensures constant remuneration by covering the difference between the expected remuneration and the electricity market price. The explosion in market electricity prices can lead to reversed cash flows as in **France**, with 724 million EURO (761 million USD) of revenue being injected back to the government, validating the model.

Competitive tenders are run by both state organisations but also utilities looking to secure increased supply and security of supply on one hand and reduce supply costs on the other. Competitive tenders have been adopted in many countries around the world, with the clear aim of increasing the competitiveness of PV electricity.

# PV MARKET DRIVERS AND SUPPORT SCHEMES / CONTINUED

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 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**. In the Middle East and Africa, tenders were issued in **Israel**, **Morocco**, **Iran**, **Saudi Arabia** as well as the **Ivory Coast**, **Mauritius**, **Botswana** and **South Africa**. In North America both **Canada** and the **USA** ran tenders at state or utility levels. In Latin America, **Argentina**, **Brazil**, **Chile**, and **Peru** continued to use tenders – although **Brazil**'s A-5 tender with over 10000 registered solar participants was suspended due to "irregularities". In Asia, many countries continued with their tender schemes including **India**, **Nepal**, **Uzbekistan**, **Sri Lanka**, but also the **Philippines**, **Malaysia**, **Japan** and **South Korea**, and **Australia** has tenders run by states and utilities.

### Competitive tenders and the market

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. Despite the rising cost of PV over 2021 and 2022, competitive bids as lows as 26 USD/MWh (**India**, **South Africa**, **Türkiye**) were made across the world (up from 2020/2021 lowest bids) – although Western European countries with lower irradiation and higher overall costs couldn't follow, with prices closer to 60 USD/MWh for utility scale ground mounted systems and up to 90 USD/MWh (**Germany**, **France**) for smaller building mounted systems.

Prices were steadily decreasing up to 2021, when the downwards price trend halted due to module price hikes resulting from a combination of COVID and demand impacts. 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 a good visibility on price pressure and are most likely to be able to price their projects to winning bids.

The past years has demonstrated how low the bids can go under the constraint of competitive tenders. However, 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, could become a threat to the long-term stability of some market actors, hence creating more market concentration. 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 over 2021/2022. As a result, in some countries projects were either delayed (**Spain**) or requested and were granted a structural intervention to revise support mechanisms (**France**).

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. Despite this, the rise in market electricity costs has meant that increasingly developers are looking to corporate clients to sell their electricity (corporate PPAs) (**France**, **USA**), or even directly to electricity markets (merchant PV) (**Spain**, **Germany**, **Australia**) – or submitting increased prices in tender bid processes.

As a result, there were a number of undersubscribed or under awarded tenders – for example the self-consumption tenders in **France**, the 3rd and 4th REER tenders in **Spain**, **Japan**'s 13th round of utility scale tenders, and tenders in **Poland**, **Croatia** – and this, even in countries where tender volumes have been increased as support mechanisms are stepped up to respond to new engagements on climate imperatives (**Germany**, **France**).

### Trends of segment specific tenders

Tender specifications can be used to push the development of specific market segments, whether it be in terms of size (between two thresholds, as in **South Korea**, **France**, **Malta**, **Poland**) or in the type of PV mounting with separate tenders or designated volumes in tenders for PV on buildings and ground mounted systems (**France**, **Germany**, **Switzerland**, **Moldovia**). There is a clear trend to specific tenders or tender volumes for agrivoltaics (**France**, **Luxemburg**, **Israel**). **Portugal** launched a tender in 2020 for floating PV. It 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**, **Germany**. In the past, innovations have been varied but there was a clear trend towards agrivoltaic systems being successful candidates.

### Trends of technology-neutral tenders and premium for local content

Tenders are often technology-specific; however, technology-neutral tenders are spreading. In this case, PV is put in competition with other generation sources. Some countries such as **Canada**, **France**, **Germany**, **Spain** and **Italy** have experimented with mixed auctions based on solar and wind in parallel with some technology-specific tenders.

In some countries, cost-based tenders evolved towards multiple-factor tenders. Environmental or industrial constraints are introduced to give an advantage to local companies or to favour a better environmental footprint of the products. Competitive tenders can be used to promote specific technologies or impose additional constraints such as local manufacturing to boost the local industry. In several countries, a local content parameter has been discussed and acts as an additional primary or secondary key in the grant decision. This type of requirement aims at enabling the development of local solar module manufacturing. **Türkiye**, for instance, applies a premium for local content, on top of the normal FiT. In some African countries such as **Algeria**, **Morocco** and **South Africa** there are no mandatory requirements for local content, but it is recommended and bids with local content are favoured. Currently, the use of local labour is the most common form of local content and there have not been follow-on benefits for local manufacturing.

The European Union is working on eco-design and environmental footprint frameworks. In **France**, a maximum level of carbon footprint is set to access the tenders and lower carbon footprints gain bonus points to facilitate winning capacity. Even if it is not directly a local content specification, local manufacturing is indirectly encouraged by the measures based on environmental impact. Low carbon footprints are also selection criteria in tenders in **South Korea**.

Tenders may not have shown their full potential yet. They are mostly used to frame PV development and PV costs. For regulators, this implies defining a maximum capacity and selecting the cheapest suitable plants to develop. However, they can be further developed and be used to guide towards larger, long-term roadmaps on power capacity and segment development. By planning smartly, together with transmission grid operators, tenders can allow to develop specific capacities for defined technologies, optimize the grid and anticipate the energy transition as a tool to support local industry.

## INCENTIVIZED SELF-CONSUMPTION

Self-consumption, supported by different mechanisms such as net-metering and net-billing is growing as electricity prices grow. Various forms of support to self-consumption schemes exist. The first set of policies used to develop the market of small-scale PV installations on buildings were called "net-metering" policies and were adopted in a large number of countries, although with different definitions of what, precisely, net metering meant. One must be careful when looking at self-consumption schemes since 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.

Genuine "net-metering" which offers credits for PV electricity injected into the grid, has previously supported market development in **Belgium**, **Canada**, **Denmark**, the **Netherlands**, **Portugal**, **South Korea** and the **USA**, but such policies are increasingly replaced by self-consumption policies favouring real-time consumption of PV electricity (also called net-billing), often completed 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 **Spain**, **France** and since 2022 California (**USA**) – where the shift has gone to net billing with time of use rates that encourage the use of storage in the **USA**'s most significant market. As a result, self-consumption is becoming a major driver of distributed PV installations. Although net-metering is being abolished in historical markets, countries such as **Thailand**, **Malaysia** or **Ecuador** introduced net-metering for residential PV owners recently. Several emerging PV countries have implemented net-metering schemes in recent years (**Chile**, **Israel**, **Jordan**, **UAE** (Dubai) and **Tunisia**). While the 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.

# PV MARKET DRIVERS AND SUPPORT SCHEMES / CONTINUED

## DIRECT SUBSIDIES, REBATES AND TAX BREAKS

Direct subsidies are still a common type of support for PV. Most of the time they cover only a part of the total installation cost. PV is characterized by limited maintenance costs, no fuel costs but high upfront investment and this has led some countries to put policies in place that reduce the upfront investment to incentivize PV. Direct subsidies were implemented in the early phase of PV development in countries such as **Austria**, **Australia**, **Canada**, **Finland**, **Italy**, **Japan**, **South Korea**, **Lithuania**, **Norway**, and **Sweden** just to mention a few.

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 some additional ones. Municipalities are more and more 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.

In most countries this support mechanism has not demonstrated its ability to support and accelerate PV development over the long term and was progressively replaced by FiTs, although not completely phased out everywhere. In 2021 and 2022, governments launched new schemes to promote specific sectors such as residential, rural or agricultural systems, bucking the trend of phasing out direct subsidies. However, there are still countries introducing this type of support mechanism; Such a comeback can be questioned as subsidies are a constraint to PV development, since they depend on public funding, which is, by nature, limited. However, they are easy to set up which explains their utilization and depending on local culture can be more attractive to end users than deferred payments through FiT.

A number of countries continue to maintain capital subsidies or even set up new schemes, with varying criteria across the world. Subsidy bonuses are not uncommon, generally going to market segment that state governments wish to promote and develop – **France** reserves its direct subsidies to self-consumption and BIPV systems and combines it with a FiT. **Switzerland** gives bonuses on top of its direct subsidies depending on the size, inclination, and altitude of systems. In **Australia**, Victoria subsidises residential systems, whilst in 2022, **Japan** joined **Finland** with subsidies for agricultural systems and sometimes systems on other specific land usages. **Austria** launched a new framework in 2021 that includes investment subsidies, and **Norway** increased the upper threshold for residential systems as well as the subsidy rate in 2022. **Poland** modified its subsidy scheme in April, after high uptake sparked a very dynamic market since 2019. The **USA** has a diversity of state and local subsidies for solar installation, often targeted at increasing deployment in low-income communities, many of which were expanded in 2022. 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.

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**).

Tax credits have been introduced (or re-introduced) in the past few years including in **Germany** (2022), **Italy**, **Sweden** (2015, 2021). Tax credits can be open to individuals (**USA**, **Italy**, **Switzerland**, **Germany**, **Finland**, **Sweden**) or commercial entities (**USA**, **Switzerland**, **Germany**, **Sweden** (limited to small systems)), and operate on 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 a tax credit bonus is granted for meeting a certain threshold of domestic content).

## 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, explained by the greater complexity of this type of scheme. Green certificate trading still exists in countries such as **Belgium**, **Norway**, **Romania** and **Sweden** (being phased out). Similar schemes based on RPS exist in **Australia**, **South Korea** and some states in the **USA** . 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. State incentives in the **USA** have been driven in large part by the passage of Renewable Portfolio Standards (RPS) whilst in **Belgium**, all three regions use the trading of green certificates for commercial and industrial segments.

## PV DEVELOPMENT WITHOUT FINANCIAL INCENTIVES

An increasing volume of the market became independent of support schemes: this implies installations not financially supported and developed outside of tenders or similar schemes. This is a sign of the PV market becoming highly competitive. The increase in energy costs in 2021 and 2022, and specifically electricity prices, have enhanced PV competitiveness in numerous countries. PV development without financial incentives is an important improvement, as it becomes independent of any support scheme limitation.

### Power Purchase Agreements

Power Purchase Agreements (PPAs) are long-term private contracts between a PV producer and one or several consumers or electricity resellers. While FiT 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 revenues and are increasingly popular for unsubsidized PV because the cost per kWh is negotiated between the parties: in times of high electricity prices (2021, 2022), the PV producer has an advantage. Such contracts were initially deployed in the wind industry but their potential for PV has grown, and electricity sold on electricity markets or through PPAs has been seen in an increasing number of countries in 2022, following on strong development in 2021. 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 PPAs (CPPAs), where the buyer is a consumer. 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; whilst PPA contracts are mostly medium to long term (10 to 25 years), the recent high electricity market prices have seen a surge in short term (2 to 3 year) contracts as producers look to the highest returns.

These non-subsidized models are gaining momentum, mostly for utility-scale PV and the trend is clear. In Europe, there was growth in the announcement and signature of corporate PPAs, as opposed to PPAs with utilities, despite an uncertain market as Europe discussed price caps on energy markets. In 2022, in general terms, **Spain** was the leading the PPA market in Europe, the **USA** in the Americas and there were strong volumes of PPAs in **India**. Despite conjunctural PV price increases in 2021 and 2022, the reduced LCOE of PV has seen the continued development of PPAs in **France**, **Poland**, **Germany**, **Denmark**, **UK**, **Italy**, and **Sweden** in Europe. The Asia-Pacific region had fast paced growth with the largest volume of PPAs announced for the first time in 2022, with projects in **India**, **China** and **Bangladesh** as well as **South Korea**, **Taiwan**, **Philippines**, **Indonesia**, **Thailand**, and **Australia** in Asia and **Saudi Arabia** in the MENA region. Other countries have been working towards structural changes to electricity markets to allow PPAs in the near future, such as **Vietnam**, **Malaysia**). 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 for the emergence of this type of business model as the market should provide both short term and long-term incentives. **Norway** saw its first project licensed in 2022, **Australia** has 18% of its nearly 20 GW capacity exposed to spot markets, **Hungary** and **Italy** already have merchant PV systems. Experts estimate that up to half of future utility scale projects in **Spain** could be merchant PV.

### 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 reduces, self-consumption has become an obvious choice in many markets – particularly in European markets or markets where electricity prices were disrupted due to the **Ukraine** conflict (**Australia**).

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 where 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** was 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.

The arrival of new schemes based on the different concepts of energy communities (collective ownership / consumption) could enlarge the market but also increases complexity, while in some countries the trend towards PV plus storage to increase self-consumption rates (such as in **Germany**, **Australia**) also paves the way for a different way of looking at the development of PV for distributed installations.

# PV MARKET DRIVERS AND SUPPORT SCHEMES / CONTINUED

### Innovating Financial Solution Support

An increasing number of investment solutions have emerged for the financing of solar installations, particularly relevant in the case of unsubsidized PV. The high upfront capital requirements are pushing different business models to develop, especially in the **USA**, and to a certain extent in some European countries. PV-as-a-service contributes significantly to the **USA**'s residential market for instance, with the idea that PV could be sold as a service contract, not implying the ownership or the financing of the installation. 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. Such business models represent already more than 50% of the residential market in the **USA**, and some utilities in **Germany**, **Austria**, **Sweden** and **Switzerland** are starting to propose them. The **USA** remains innovative by the existence of pure players proposing PV as their main product, solutioning many barriers to financing and effective operations, as well as reducing the uncertainty in the long-term for the prosumer. It is possible that such services will further develop.

Similarly, pay-as-you-go financial models have been very successful in the deployment of Solar Home Systems (SHS) and solar kits in African countries in the past years and are expected to further drive the development of PV in the residential and off-grid segments. Pay-as-you-go models are directly inspired from prepaid mobile payment schemes; the users pay a monthly fee or according to their needs and own the solar kit when enough credits have been paid.

# PROSUMER AND ENERGY COMMUNITY POLICIES

## SELF-CONSUMPTION IN REGULATORY ENVIRONMENTS

Prosumer (self-consumption) regulations are increasingly being implemented in different countries with the double goal of empowering consumers to play an important role in the energy transition and reduce the cost of support mechanism for the development of renewable energies. Measures in favour of distributed generation are stimulating greater use of renewable sources with further positive effects such as a stronger penetration of electricity in final consumption, the reduction of transmission and distribution costs and new investments in integrated energy management projects (electricity, heat, efficiency, storage, etc.).

Self-consumption is allowed one way or another in many countries but the regulations in place differ significantly with both structured and ad hoc legal frameworks, although the physical principals of self-consumption are always the same: the electricity that is produced by the PV system and locally consumed reduces the quantity of electricity on the consumers bill. However, this reduction is not implemented in the same way in all countries. It is generally accepted that variable grid costs on the part of PV electricity that is self-consumed should not be paid, however different countries have taken different approaches to adapting their fee structures for the rise in self-consumption. Some have modified the structure of grid tariffs (increasing the fixed part and reducing the variable part linked to consumption) to maintain revenue from prosumers. Specific grid taxes are starting to be implemented in some countries, with the aim to compensate for saved grid costs due to net-metering/billing policies.

In **Australia**, **France**, **Switzerland**, the shift from variable to fixed grid costs is debated actively and could lead to a change in the electricity tariff structure that could be detrimental to the development of self-consumption. In the **USA**, net metering is available in many states, but 2022 did see intense debates in several states with large solar markets on net metering successor tariffs aimed at reducing "cost-shifting" from PV to non-PV customers and compensate PV based on its value to the grid. In general, there remains a diversity of approaches regarding the use of grid access fees, minimum bills, and time-of-use rates in the **USA**. The case of **Israel** is more specific, with dedicated taxes for balancing and back-up. The Spanish grid tax is the only example of a specific tax for pure self-consumers. In several regions in **Belgium** a grid tax will be implemented for prosumers benefiting from net-metering which allows full compensation of their PV consumption, grid cost included.

Some countries have exempted self-consumption systems from variable grid access fees, or even from other grid access fees. Some countries impose specific grid codes on PV system owners who are self-consuming electricity. In **Australia** for instance, grid injection limits exist in some states. **Denmark** and **Germany** amongst others requires compliance with specific grid codes for self-consumption systems. In most countries, the ownership of the PV system can differ from the electricity consumer, however some countries either do not allow this or have yet to find a regulatory solution to allow it (for example **Denmark**, **France** where there is a complex situation with national regulations and no clear pattern appears today regarding third-party ownership).

## COLLECTIVE SELF-CONSUMPTION

Collective self-consumption enables the sharing of electricity between several users, sometimes between distinct individual buildings. Self-consumption in collective buildings or sites allows one or more production units to feed their electricity to several consumers, using a predefined split key that can be static or dynamic. The typical case concerns a multi-apartment building, with one single PV plant feeding several or all consumers in the building.

The use of self-consumption in collective buildings exists in **Portugal**, **Spain**, **Austria**, **Canada**, **Sweden**, **France**, **Switzerland**, **Germany**, **USA** or **Italy** to mention a few, and is being set up in **Norway**. Depending on local contexts, collective self-consumption is also developed with the aim of widening the perimeter of self-consumption, allowing 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. Widening the perimeter to include several consumers and generators has advantages for participants that include increased self-consumption ratios and more equitable access to roof and land for self-consumption purposes – it can also be a lever to increase uptake for social reasons or include fragile consumers.

These schemes allow self-produced electricity to reduce the PV system owner's electricity bill, on-site or even between distant sites (**Mexico**, **Brazil**, **France**). Various schemes exist that allow compensation for electricity consumption and PV electricity production – some compensate for real energy flows, while others are compensating for financial flows. While details may vary, the basics are similar.

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.

In **Italy**, changes under discussion in 2022 would add incentives for systems up to 1 MW, participating in projects on the same distribution substation. In **Sweden**, it had been allowed through microgrids in 2021. In **France** since 2021 virtual self-consumption within a building, a 2 km, or exceptionally, a 20 km geographical perimeter is allowed and excess electricity can access FiT's. In **Germany**, building owners can produce and sell electricity to their tenants which makes the investment more attractive. The **UK** has also implemented a favourable framework for collective prosumers. 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. Other countries have some definitions, but these are not yet fully implemented. In **Austria**, **France**, uptake is slow but higher retail prices of electricity, and the introduction of EU defined energy communities is expected to accelerate the movement.

Network pricing regulations in **Australia**, **France**, stipulate that full network charges must be paid even for locally transmitted electricity, which acts as a barrier to collective self-consumption or virtual net-metering (exceptions are possible in **France**). In **Switzerland** collective self-consumption is allowed by most grids, but consumers have to be contiguous and not use the public grid. 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.

## ENERGY COMMUNITIES IN THE EU AND USA CONTEXT

While self-consumption is allowed in most European countries, Europe has decided to go a step further with the comprehensive update of its energy policy, the "Clean Energy Package". The European Union introduced new provisions on the energy market design and frameworks for new energy initiatives. Specifically, the actual recast of 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 the member states that is slowly being deployed across Europe. This concept of energy communities is likely to expand the existing PV market segments and allow cost reductions for consumers not able to invest in solar installation themselves.

A different definition of an energy community is emerging in the **USA**. As a result of the passage of the Inflation Reduction Act, the term "energy community" has begun to take on a distinct meaning, referring 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. (see below).

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### DELOCALIZED OR "VIRTUAL" SELF-CONSUMPTION

While self-consumption could be understood as the compensation of production and consumption locally, distributed (or "Virtual") self-consumption expands to delocalized consumption and production and opens a wide range of possibilities involving ad hoc grid tariffs. In that respect, prosumers at district level would pay fewer grid costs than prosumers at a regional or national level. In the **USA**, nearly half of the states have passed legislation enabling delocalized collective self-consumption (referred to within the **USA** as "community solar"), with many including requirements for participation of low-income households. Federal incentives for community solar also became available in 2022 with the passage of the Inflation Reduction Act. Some European utilities have launched pilot projects before regulations were officially published (as in **Austria** or **Switzerland**). In this case, innovative products are already mixed with PV installations, PV investment and virtual storage. This evolution will be scrutinized in the coming years since it might open new market segments for solar PV. But these schemes create complex questions, especially regarding the use of the grid, the legal aspects and technical complexity related to compensating electricity between several meters and the innovative aspect of the scheme.

The opportunities opened up by such concepts are wide-ranging. For instance, this could allow charging an electric vehicle at the office with PV electricity produced at home or sharing the PV electricity in all public buildings in a small town between them depending on the consumption or installing a utility-scale plant in the field near a village to power inhabitants. Options are numerous and imply fair remuneration of the grid to be competitive for all. Using PV electricity in a distributed location implies the use of the public grid, distribution or even transmission and would require putting a fair price on such use. With PV becoming competitive, such ideas are emerging and could develop massively under the right regulations.

## 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.

For instance, in **France**, the lower threshold for mandatory solar or living roofs for commercial and industrial buildings or covered car parks has been decreased, and new types of buildings added, making many more buildings subject to the requirements. In addition, regulations were added to make solar canopies mandatory on many car parks. In **Austria**, many counties have regulations or incentives for building a PV system. Up to now in Vienna and Styria it is mandatory to install a PV system under certain conditions. In **Germany**, in **Berlin**, solar will be mandatory on many new buildings by 2023 whilst in the **Netherlands**, buildings must aim to be nearly energy neutral since 2021, pushing solar. In **Switzerland**, mandatory solar is being rolled out across different cities for new and/or renovated buildings in **Belgium**, Flanders introduced measures in 2014 with PV now on more than 85% of new buildings. In **Denmark**, the national building code has integrated PV to reduce the energy footprint, whilst in **Italy**, capital subsidies have been introduced to promote PV on public buildings in Lombardy. In **Japan**, Tokyo will be requiring solar on most residential buildings, and other smaller buildings from 2025. In **South Korea**, the NRE Mandatory Use for Public Buildings Programme requires 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 is set to extend this to non-residential and high-rise multifamily buildings in 2023 as well as expand the mandate to require a solar plus storage system, rather than just a solar system. In **India** some states have mandatory solar supply policies for new buildings.

## ELECTRIC MOBILITY

The electrification of transport is accelerating in many countries and whilst the link between PV development and EVs is not yet fully understood, the growth of self-consumption policies and grid congestion limiting injections are factors to be considered. Charging EVs during peak load implies rethinking power generation, grid management and smart metering, and concepts such as virtual self-consumption could rapidly provide a framework for EV's as mobile storage for excess PV generation. With 10.5 million EVs sold in 2022 (+60% on 2021), the growth curve of EV sales crossed that of PV this year, demonstrating an accelerated development beyond that of PV.

In Europe, national and local-level actions exist to support EV deployment, both with incentives for those buying EV's or investing in charging stations, but also in terms of barriers for traditional internal combustion vehicles. In **Austria**, the purchase of electric vehicles for private use is supported and proof of the use of electricity from 100% renewable energy sources is a fundamental part of the support mechanism, which is the clear link to own PV production or electricity consumed from hydropower, PV, and wind.

Outside of Europe, many countries with dynamic PV markets also have strong financial incentives for electric passenger vehicles and charging stations (**Japan**, some states in **Australia**, **India**). In 2022, the **USA** implemented significant national incentives for the purchase of EVs via the Inflation Reduction Act. In contrast, **Norway**, **Sweden** and **China** supported the roll out of electric vehicles for many years but are now stepping down or have already stopped incentives.

## HYDROGEN PRODUCTION

The invasion of Ukraine by Russia and the international sanctions that followed pushed gas prices upwards. This increased announcements of investments in green hydrogen in Europe, although most investments have yet to be confirmed as uncertainty around the perennity and calendar of the favourable conditions remains. Solar fuels, storage and other hydrogen-based applications will require massive PV, wind and other RES development. Distributed Hydrogen production could be driven by distributed PV as well, pushing for higher demand for distributed PV-H2 production. This is still a distant prospect and significant developments before 2025 in Europe are unlikely, although other regions may move faster where this could start to become a business reality around 2025. The EC expects green hydrogen to play a pivotal role in the decarbonisation of sectors where electrification might be less feasible and to bridge some of the gaps for seasonal variations which is crucial for the further development of solar PV. The EU has published strict guidelines on the definition of "green" hydrogen, including hourly matched RES electricity generation from "new" sources, rules that are expected to contribute to the further deployment of solar for $H_2$ production. Several funds are available to promote research and pilot projects to increase the competitiveness of green hydrogen and the EU industry has developed an ambitious plan to reach between 15 GW and 40 GW, on a low and high case scenario respectively, of electrolysers in Europe by 2030. The **USA** saw significant investment in hydrogen development, infrastructure, and production (including the institution of a tax credit for hydrogen production in the Inflation Reduction Act (IRA)) in 2022. In **China** the world's largest PV to hydrogen project neared completion, with a capacity equal to all other projects commissioned in 2022. Announcements of projects for large scale solar + hydrogen production around the world have increased (**Australia**, **USA**, **Spain**, **Germany**, **France**, **UAE**, **Oman**, **Mauritania**).

## ELECTRICITY STORAGE

In the current stage of development, electricity storage remains to be incentivized to develop in most parts of the world. However, the cost of storage is pursuing its steep decline 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 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.

Amongst the countries that have issued laws to incentivize battery storage for PV systems in 2022, **Austria**, supports the combination of new or existing PV systems with electricity storage if storage capacity is at least 0.5 kWh per kW peak is installed. In **Australia**, most states offer some type of incentive for solar plus battery installations or to add a battery to an existing solar system. Government funding was made available for 8 big batteries (over 200 MW/400 MWh each) in December 2022, and there was over 2 GWh of large-scale storage in construction by the end of 2022 in **Australia**, with newer projects increasing in scale. In the **USA**, California and Texas have added a combined 3.7 GW of storage, or 90% of the national market, and these states are also the biggest solar markets in the country. As noted above, California (**USA**) also expanded its mandate for solar on new buildings to include a storage requirement as well and whilst in previous years national incentives required storage to be connected to solar, the IRA has facilitated standalone storage through tax credits.

Storage is a key element of a carbon neutral energy system relying on RES electricity; therefore, the European Commission actively supports energy storage through research and innovation funds. Some consider that storage development for PV electricity will be massively realized through electric vehicles connected to the grid during a large part of the day and therefore will be able to store and deliver energy to consumers at a larger scale than simple batteries. This vehicle-to-grid (or V2G) concept is 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

COVID-led supply chain disruptions and increasingly ambitious climate change actions saw many initiatives favouring local manufacturing at various steps of the PV value chain in 2021, and 2022 both confirmed and accelerated the trend, with governments around the world supporting local manufacturing through policies, subsidies and regulations – from tax credits to direct subsidies to reduced administrative barriers for local content.

Some of the most significant acts of the past decade were launched in 2022, including the Inflation Reduction Act (IRA) in the **USA** and the preparation of a series of EU-level policies in **Europe**. The IRA was promulgated in August 2022 and the generous tax incentives for local manufacturing, critical mineral refining, and recycling have triggered many announcements for new manufacturing capacity in the **USA**. In **Europe** a series of policies planned in 2022 but published in 2023 are intended as landmark acts in the EU Solar Energy Strategy (within the REPowerEU plan) - the Green Deal Industrial Plan (published in February 2023), the Net-Zero Industry Act (NZIA) and the Critical Raw Materials Act (both published in March 2023), and the Net Zero Industry Academies were enacted, stimulating and encouraging local manufacturing plans. Changes to the Carbon Border Adjustment Mechanism may also have positive impacts in Europe. Amendments to the Temporary Crisis Framework at the end of 2022 and again in 2023 lift limitations for Member States to grant direct aids, with solar manufacturing being entirely eligible. Co-funded by the EU and launched late 2022, the European Solar PV Industry Alliance aims to facilitate innovation-driven expansion of a resilient industrial solar value chain in the EU, particularly in the PV manufacturing sector. A PV Important Projects of Common European Interest (IPCEI) has been worked on through 2022. These EU level actions have been complemented by national measures planned over 2022 in the **Netherlands**, **Spain** and **Germany**, that may come into action in 2023. In **India**, state financing for local manufacturing is available through the Production Linked Incentive Scheme that was continued in 2022, with three winners in Round 1 – and more than ten announced in further rounds in 2023, a first step to building dozens of GW of domestic manufacturing capacity capable of supplying a large proportion of the local, growing PV market. In **Türkiye** a new YEKA (Renewable Energy Resource Area) call for tenders was expected but not published in 2022 – the YEKA calls give priority to areas and RES projects that can be supplied with domestic manufacturing and have proved successful so far.

In **China** industry and government has acted to maintain its position as the pre-eminent manufacturer of PV, and with massive private investments over 2022 they have in fact triggered overcapacities in large scale manufacturing, bringing down module prices to near cost in 2023 and creating a natural barrier to entry for new manufacturers in other countries. A public consultation was launched in 2022, as the authorities are considering a ban on exports of equipment to manufacture ingots and wafers.

Whilst there is a clear push to develop support for local manufacturing across the world, there is not always a clear understanding of the industry dynamics and the complexities of PV manufacturing, which will lead to fewer real projects than what some governments would like to see – added to which, as the proportion of global supply of specific raw materials (silver, glass for example) devoted to PV increases, local manufacturing will imply access to global value chains and the role of already existing global actors shouldn't be neglected.

Photo by TRYBA ENERGIES

# four

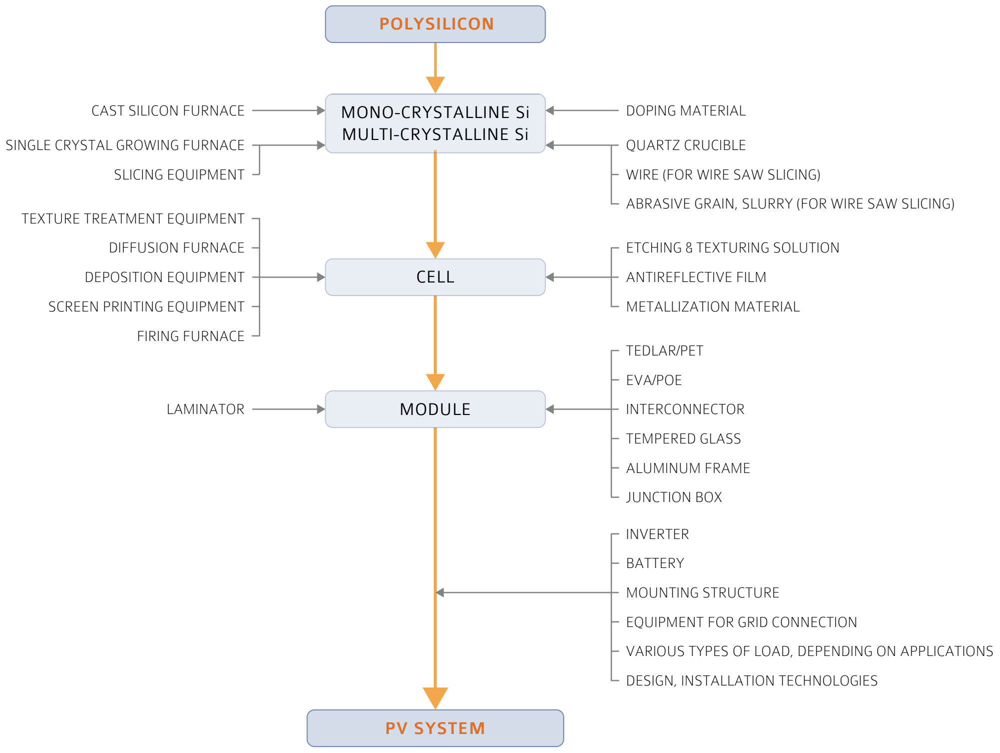
## TRENDS IN PV INDUSTRY

This chapter provides a brief overview of the upstream and downstream sectors of the PV industry intending to provide highlights during 2022 and the first half of 2023. The first part provides manufacturing activities of the upstream sector of the PV industry from feedstocks (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 2022, as in 2021, trends of PV module and other component prices increasing were observed that affected planned projects. The price level of PV modules remained high in 2022 as it is greatly affected by polysilicon prices. However, polysilicon prices declined from the fourth quarter of 2022 onward as polysilicon production gradually increased due to the operation of newly built polysilicon plants. Wafer prices also declined due to the expansion of production capacity and PV module prices gradually declined as well. Shortage of semiconductors also impacted inverter supply and some inverter manufacturers reported delays in shipments even in the first half of 2023.

In 2022, **China** remained the world's largest producer along the PV supply chain and further enhancement of manufacturing capacity was reported. While PV power generation is expected to take a significant role in the energy transition, the risks linked to heavy manufacturing concentration in one country have been highlighted, initiating policy development and measures in support of local manufacturing in the **USA**, **India** and Europe. Political stances over trade conflicts and forced labour are also drivers of local manufacturing. However, since investment in production capacity in **China** remains active, **China**'s dominant presence in the supply chain is expected to continue for the time being.

**FIGURE 4.1**: PV SYSTEM VALUE CHAIN (EXAMPLE OF CRYSTALLINE SILICON PV TECHNOLOGY)



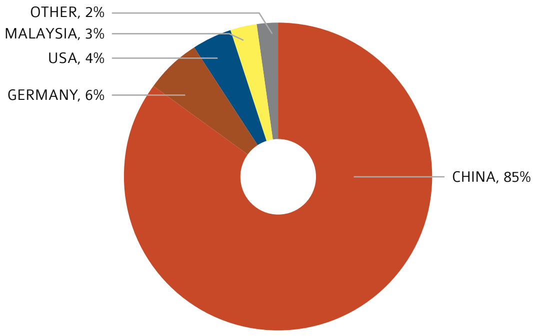
SOURCE IEA PVPS & OTHERS.

# THE UPSTREAM PV SECTOR

## POLYSILICON PRODUCTION

Wafer-based c-Si technology remains dominant for producing PV cells. Hence, this chapter focuses on the wafer-based production process. The global polysilicon production (including semiconductor grade polysilicon) in 2022 was about 1 001 350 tons, exceeding a million tons for the first time. Production of polysilicon for PV cells increased from 604 812 tons in 2021 to 955 575 tons in 2022 and production of polysilicon for semiconductors was 45 780 tons. The production volume of polysilicon for PV cells accounted for about 95% of total production of polysilicon in 2022. Global polysilicon production capacity (including production capacity for semiconductors) increased from 813 100 tons/year in 2021 to 1 354 700 tons/year in 2022. Accumulating polysilicon production enhancement projects planned mainly in **China**, the global polysilicon production capacity as of the end of 2023 could exceed 2.8 million tons/year. Figure 4.2 shows the share of polysilicon production by country.

**FIGURE 4.2**: SHARE OF PV POLYSILICON PRODUCTION IN 2022



SOURCE IEA PVPS, RTS CORPORATION
* INCLUDING POLYSILICON FOR SEMICONDUCTORS

IEA PVPS member countries producing polysilicon are **China**, **Germany**, the **USA**, **Malaysia**, **South Korea**, **Norway** and **Japan**. **China** continued to be the largest producer and consumer of polysilicon in the world. **China** produced 857 000 tons of polysilicon in 2022, accounting for 86% of the global production. In 2022, a total of 541 600 tons/year of new polysilicon production capacity was established. The number of polysilicon manufacturers in **China** increased from 12 in January 2022 to 15 by the end of 2022 and is expected to increase to more than 20 by the end of 2023. If all new and expanded polysilicon plants start operation as planned, there could be a significant oversupply. **China** produced more than 600 000 tons of polysilicon in the first half of 2023, a 65% increase from the same period previous year.

The second largest polysilicon producer is **Germany**, which has 60 400 tons/year of polysilicon production capacity. Out of 58 000 tons of polysilicon produced, about 47 000 tons is considered to have been consumed for PV. The third largest producer is **Malaysia**, which produced 32 300 tons of polysilicon for PV cells with 35 000 tons/year of production capacity. In **Malaysia**, **South Korea**'s OCI is producing polysilicon, which announced the policy to enhance production capacity further to actively meet the increasing demand of polysilicon made outside **China**. OCI plans to fully operate its polysilicon plant in **Malaysia** and promote a phased expansion of 30 000 tons/year scale over the next five years. Since the Chinese government imposes tariffs on US-made polysilicon, it is analyzed that the **USA** produced 38 000 tons of polysilicon, mainly for the semiconductor industry. However, demand for polysilicon manufactured in the **USA**, and indeed all non-**China** polysilicon, saw an increase in 2022 as a result of accusations of forced labour within **China**. This demand, combined with the subsidies within the Inflation Reduction Act (IRA) for the production of solar polysilicon, is expected to increase solar polysilicon production within the **USA**. For example, REC Silicon plans to resume polysilicon production at its Moses Lake plant in the State of Washington in the fourth quarter of 2023. In **Norway**, approximately 3 000 tons of polysilicon is estimated to have been produced in 2022. **Norway** reported activities of polysilicon manufacturers adopting the metallurgical process aiming at lowering production costs. In **Japan** and **South Korea**, polysilicon production is mainly for the semiconductor industry. Although there are no polysilicon producing countries among non-IEA PVPS member countries, polysilicon production is planned in **India** using government incentives.

Polysilicon prices remained high as the supply and demand gap remained unresolved until the third quarter of 2022. The spot price at the end of January 2022 was 32.15 USD/kg. Thereafter, it remained in the lower 30 USD/kg range and rose to 35.13 USD/kg at the end of June 2022, affected by a fire at a polysilicon plant in **China** and electricity power consumption control by the government. It further rose to 38.32 USD/kg at the end of July as several companies went into periodic maintenance. Polysilicon production increased from September and the spot price remained in the 35 USD/kg range until the end of October. It dropped to 33.58 USD/kg at the end of November and then to 23.21 USD/kg at the end of December, when production expanded. The price dropped to 15.86 USD/kg in January 2023. This price is the lowest level since March 2021.

With the improvement of conversion efficiency of PV cells and modules and efforts to reduce the use of materials (thinning and increasing size of wafers), the amount of polysilicon used for 1 W of wafer (consumption unit of polysilicon) has been decreasing year after year. While the estimated average amount of polysilicon used for a solar cell was 2.7g/W in 2021, it decreased to 2.3 g/W in 2022. Compared to 6.8 g/W in 2010, the consumption unit of polysilicon has been decreasing at a pace of about 8.7%/year.

Most major polysilicon manufacturers use the Siemens process, which has been conceived as a manufacturing process of polysilicon for the semiconductor industry. It is estimated that the Siemens processed polysilicon accounted for 98% of the total production. Reported production efficiency has improved, and the energy consumption of the whole process to produce polysilicon decreased from 63 kWh/kg in 2021 to 60 kWh/kg in 2022.

The decrease of electricity consumption in the reduction process using the Siemens method has been achieved by efforts including the following:

1. development and commercialization of large-scale reduction furnaces;
2. improvement of inner wall materials of the furnace;
3. replacement of conventional silicon tube with silicon core, and adjustment of gas mix.

## THE UPSTREAM PV SECTOR / CONTINUED

It has been said that electricity consumption can be reduced further by the optimization of the process and economies of scale, which is assumed to contribute to the reduction of polysilicon prices. Besides the Siemens process, fluidized bed reactor (FBR) is used to produce polysilicon. Advantages of the process are lower energy consumption and granular shaped products can be fully packed space in the crucibles. In 2022, GCL Technology in **China** started operation of three new plants that use FBR process and has 140 000 tons/year of production capacity using the FBR process (newly established production capacity of 30 000 tons/year in Xuzhou City, Jiangsu Province, 60 000 tons/year in Leshan City, Sichuan Province and 20 000 tons/year in Baotou City, Inner Mongolia Autonomous Region). The company has started production of n-type sc-Si wafers with polysilicon produced using FBR process.

In 2021, the **USA** decided to ban US imports of material derived from Chinese-based Hoshine Silicon Industry that produces metallic silicon, a base material of polysilicon, due to concerns that they were using forced labour. Then, in December 2021, the Uyghur Forced Labor Prevention Act (UFLPA) was signed into law and went into effect on June 21, 2022. As a result, the **USA** started to enforce the ban of importation of goods manufactured wholly or in part in the Xinjiang Uyghur Autonomous Region (XUAR) in **China**, under the assumption that they were the products of forced labour. Because of this measure, new polysilicon plants are planned within **China** outside of the XUAR, such as in Inner Mongolia and other regions, as well as outside of **China**. Some companies have also entered the polysilicon production business to strengthen vertical integration. For example, Trina Solar is building polysilicon production facilities in Qinghai Province. In the **USA**, REC Silicon decided to restart polysilicon production in Moses Lake with the investment guaranteed by Hanwaha Solution of **South Korea**. Due to these movements, future production locations might change but for the time being, **China** is assumed to remain the global top producer of polysilicon.

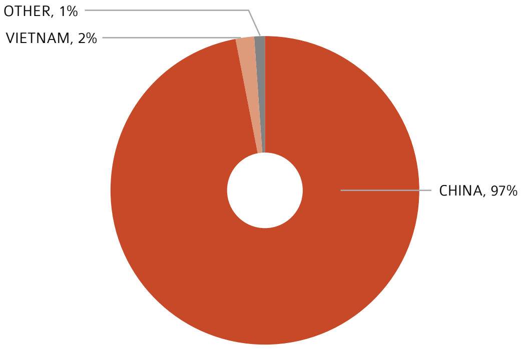
### INGOTS & WAFERS

To produce sc-Si ingots or mc-Si ingots, the basic input material consists of highly purified polysilicon. The ingots need to be cut into bricks or blocks and then sawn into thin wafers. Conventional silicon ingots are of two types: sc-Si (single crystalline silicon) ingots and mc-Si (multi-crystalline silicon) ingots. The first type, although with different specifications depending on purity and specific dopants, is also produced for microelectronic applications, while mc-Si ingots are used only in the PV industry. Ingot manufacturers are in many cases manufacturers of wafers.

In addition to major ingot/wafer manufacturers, some PV cell/module manufacturers also manufacture silicon ingots and wafers for their in-house uses. The trend was observed that some of these major PV module manufacturers which established vertically integrated manufacturing shifted to procuring wafers from specialized manufacturers because of cost and quality advantages under cost pressure. However, recently, some major companies have increased their in-house production capacity to reduce the risks associated with procurement.

Global wafer production amounted to 381 GW in 2022, a 64% increase from 233 GW in 2021. The production capacity of wafer as of the end of 2022 reached 687 GW/year from 416 GW/year in 2021. As in 2021, production capacity and volume for mc-Si wafers decreased while those of sc-Si wafers increased due to demand for higher efficiency PV modules. As shown in Figure 4.3, **China** has more than 97.5% of the global production of wafers. In 2022, **China** produced 371.3 GW of wafers, an approx. 64% increase year-on-year. Among them, around 36.3 GW of wafers were exported to other solar cell manufacturing countries such as **Vietnam**, **Malaysia**, **Thailand**, **Singapore**, **Taiwan** and **India**. Production capacity in **China** as of 2022 was 673 GW/year. Wafer manufacturing countries other than **China** include **Vietnam**, **Malaysia**, **Norway** and **Singapore**. In **Vietnam** and **Malaysia**, major Chinese solar cell manufacturers have production capacity. In **Vietnam**, approx. 6.1 GW of wafers were produced in 2022.

**FIGURE 4.3**: SHARE OF PV WAFER PRODUCTION IN 2022



**SOURCE** IEA PVPS, RTS CORPORATION

In 2022, it was notable that the share of large-sized wafers increased further. Market share of 182 mm (M10) and 210 mm (G12) wafers surged from 45% in 2021 to 82.8% in 2022. As the Chinese PV Industry Association (CPIA) estimates that these wafers will account for the most part of the market with the share of 93.2% by 2023, it is expected that large-sized wafers will become the mainstream products. In addition, thinning of silicon wafers has made progress. Efforts to reduce polysilicon consumption have made further progress and the thickness of 166-182 mm products was reduced from 160 µm in 2021 to 150 µm in 2022. The thickness of 210 mm products was also reduced to 150 µm in 2022. The thickness of products for both sizes is expected to be in the 140 µm range by 2023, indicating that the trend toward thinner wafers may progress further than predicted. Tungsten wire is being considered as an alternative to diamond wire to make wafers thinner. Module sizes, which have varied due to the increasing size and diversity of wafers, are about to be standardized in the industry. It seems that major manufacturers have agreed on a standard module size; the short side of a module will be 1.134 mm using square or rectangular wafers with a side of 182 mm and the standard size of a 66-cell products will be 1.134 mm x 2.382 mm.

The spot price of c-Si wafers generally follows the price of polysilicon. However, in the fourth quarter of 2022, a decrease in wafer prices was observed earlier than the timing of the downward trend in polysilicon prices as a result of a widening supply and demand gap for wafers due to increased production capacity. The price of 166 mm sc-Si wafers was 70.8 USD cents/piece in January 2022 and the price remained around 75 USD cents/piece in March as a result of price increase by major wafer manufacturers. The high price of polysilicon also affected the price of 166 mm sc-Si wafers, which was in the low 80 cents/piece range from August to October 2022. The price dropped to 77.5 USD cents/piece at the end of November and further declined to 52.5 USD cents/piece in December due to the elimination of the supply and demand gap. The price decline was caused by the overstock of wafers, as the production capacity of c-Si wafers expanded rapidly, while the production capacity of large solar cells did not increase as much as that of wafers. Although the price gradually rose after January 2023 to 69.7 USD cents/piece in April, it dropped to 35.9 USD cents/piece in June 2023. Besides polysilicon, short supply of quartz sand, the raw material for crucibles used in the production of ingots, also made it impossible to produce enough to meet production capacity in early 2023.

Plans for new and expanded wafer production capacity outside of **China** have been active continuously from 2021. In **India**, several companies are planning vertical production from wafers to PV modules. If the companies selected under the Production Linked Incentive (PLI) scheme for the PV industry complete their production facilities as planned, wafer production capacity is expected to reach 12 GW/year by 2024 and 41 GW/year by 2025. In the **USA**, plans to build new wafer production capacity were announced after the enactment of the IRA, and announced wafer production capacity is nearly 30 GW/year. Most announcements involved vertical manufacturing plans, for example, Hanwha Solutions of **South Korea** announced a plan to build 3.3 GW/year of c-Si ingot and wafer production capacity in the State of Georgia, **USA** to support 3.3 GW of cell and module production there. However, several announcements have also been made from manufacturers intending to solely produce wafers, such as Cubic PV's plans to build a 10 GW/year c-Si wafer plant in the **USA**. In the first half of 2023, **China**'s c-Si wafer production was more than 250 GW (more than 63% increase over the same period previous year). Within **China**, the expansion of wafer production capacity has continued, and production capacity may exceed 790 GW/year by the end of 2023. Although the diversification of wafer production locations will continue as mentioned above, **China** is expected to lead wafer production for the time being. Meanwhile, several startup companies in the **USA** and Europe are developing kerfless wafer manufacturing processes that do not use conventional ingot growth or wire saws. NexWafe (**Germany**) raised 30 million Euros to fund the establishment of a c-Si wafer plant in Bitterfeld, **Germany**.

# THE UPSTREAM PV SECTOR / CONTINUED

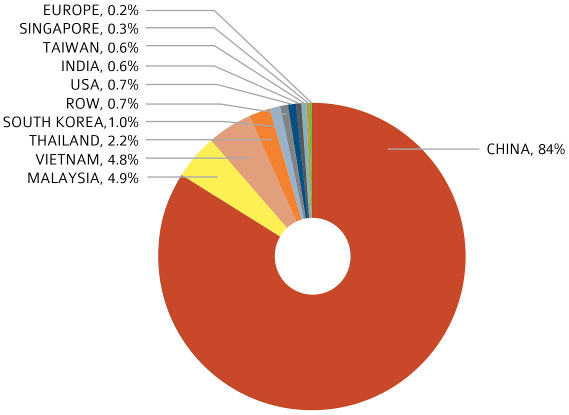
## SOLAR CELL AND MODULE PRODUCTION

### Solar Cell Production

Global solar cell (c-Si and thin-film solar cell) production in 2022 reached 394 GW, a 61% increase from 244 GW in 2021. Global solar cell manufacturing capacity was 599 GW/year as of the end of 2022. As well as the previous year, **China** was the world's largest solar cell manufacturer. **China** produced 331 GW of solar cells in 2022, a 62% increase from 198 GW in 2021. **China**'s solar cell manufacturing capacity was 506 GW/year as of the end of 2022. From 2021 onward, 145 GW/year of production capacity was added. As shown in Figure 4.4, **China**'s solar cell production volume accounts for 84% of the global total production volume.

As shown in Table 4.1, top five solar cell manufacturers are Chinese companies.

**FIGURE 4.4**: SHARE OF PV CELL PRODUCTION IN 2022



**SOURCE** IEA PVPS, RTS CORPORATION

**TABLE 4.1**: GLOBAL TOP FIVE MANUFACTURERS IN TERMS OF PV CELL/MODULE PRODUCTION AND SHIPMENT VOLUME (2022)

| **RANK** | **SOLAR CELL PRODUCTION (GW)** | | **PV MODULE PRODUCTION (GW)** | | **PV MODULE SHIPMENT (GW)** | |
|---|---|---|---|---|---|---|
| **1** | TONGWEI SOLAR | 49.2 | LONGI GREEN ENERGY TECHNOLOGY | 48.2 | LONGI GREEN ENERGY TECHNOLOGY | 46.8 |
| **2** | LONGI GREEN ENERGY TECHNOLOGY | 36.2 | TRINA SOLAR | 45.4 | JINKOSOLAR | 44.5 |
| **3** | AIKO SOLAR | 33.7 | JA SOLAR TECHNOLOGY | 43.9 | TRINA SOLAR | 43.1 |
| **4** | TRINA SOLAR | 33.6 | JINKOSOLAR | 40 | JA SOLAR TECHNOLOGY | 39.8 |
| **5** | JA SOLAR TECHNOLOGIES | 32.7 | CANADIAN SOLAR | 21.1 | CANADIAN SOLAR | 21.1 |

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

**SOURCE** RTS CORPORATION (WITH SOME ESTIMATES)

Countries other than **China** that reported production of solar cells in 2022 are **Malaysia** (19.1 GW), **Vietnam** (18.8 GW), **Thailand** (8.7 GW) and **South Korea** (4.1 GW). Europe, the **USA**, **India** and **Japan** also reported production. Figure 4.4 shows the share of solar cell production by country in 2022. Production in **Vietnam** and **Thailand** have been increasing in recent years as major Chinese solar cell manufacturers have built production bases in these countries because they are exempt from **USA** antidumping duties (AD) and countervailing duties (CVD) imposed on Chinese products. In terms of solar cell production capacity as of 2022, **Vietnam** had 27.5 GW/year, while **Malaysia** and **Thailand** had 24.5 GW/year and 14.3 GW/year respectively. In the **USA**, solar cell production was entirely composed of CdTe thin-film technology, mainly produced by First Solar.

As for c-Si solar cells, demand for high efficiency solar cells has been increasing continuously. The share of sc-Si solar cells increased from 89% in 2021 to 94.6% in 2022, while the share of mc-Si solar cells was around 2.9%. In 2022, the mainstream technology for c-Si solar cells was PERC technology, which accounted for about 88% of the market. However, as mass production of n-type c-Si TOPCon solar cells became fully operational in 2022, its market share increased from 3% in 2021 to 8.9% in 2022. In 2023, the market share of n-type c-Si TOPCon solar cells is expected to increase further to more than 20%. The market share of higher efficiency technologies such as Si-heterojunction (SHJ) and back contact including metal wrap through is not growing as much as that of TOPCon. In the future, a shift to n-type products, mainly TOPCon, is expected to progress in **China**. According to media reports, the planned cell production capacity of TOPCon technology is over 800 GW/year and that of SHJ technology is 117 GW/year.

These numbers include cell production capacity which will be established by new entrants. As was mentioned in the wafer chapter, the size of solar cells has become larger, adopting 182 mm square (M10) and 210 mm square (G12) wafers.

The spot price of solar cells has been changing following wafer prices and the supply and demand conditions in the market. The spot price of mono-PERC cells (166 mm product) increased from 16.5 USD cents/W in January 2022 to 17.5 USD cents/W in June 2022. It then remained at 17 USD cents/W from September to November but dropped to 14.5 cents/W in the end of December 2022 due to the decline in wafer prices. After that, it dropped to 10.2 USD cents/W in January 2023, then rose to 13.5 USD cents/W in March and remained on the 14 USD cents/W level after April but dropped to 11 USD cents/W in June 2023.

In the first half of 2023, **China**'s solar cell production was more than 220 GW (more than 62% increase over the same period of the previous year). JinkoSolar and Chint Solar in **China** plan to increase the share of n-type products in their total production capacity to more than 70% and more than 80%, respectively, by the end of 2023. As major manufacturers are also rapidly expanding their n-type production capacity, the share of n-type products is expected to increase, with TOPCon as the main technology.

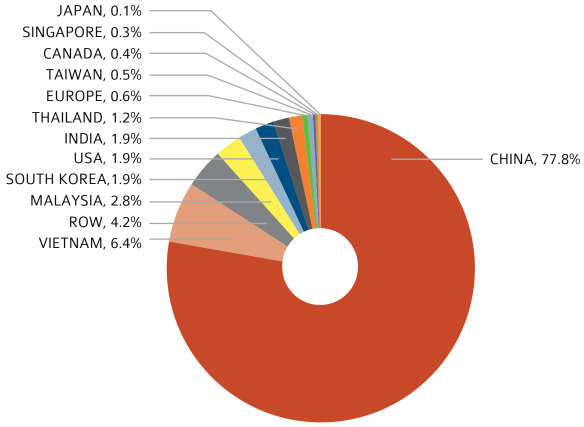
In the **USA** and **India**, solar cell production capacity is expected to increase in the future as well as wafers. In **India**, according to the plans of companies selected under the PLI scheme mentioned above, production capacity is expected to increase to 16.3 GW/year by 2024 and to 52.5 GW/year by 2025. Also in the **USA**, solar cell production capacity is expected to increase, as over 40 GW/year of c-Si cell capacity has been announced, along with nearly 10 GW/year of thin-film cell and module manufacturing capacity as a result of the incentives in the IRA. In addition, plans to build solar cell manufacturing bases have also been reported in the Middle East and Africa.

## SOLAR MODULE PRODUCTION

Following global demand for PV system installations, the global PV module production (c-Si PV module and thin-film PV module) showed an increase from 242 GW in 2021 to 379 GW in 2022. As shown in Figure 4.5, **China** continued to be the largest producer of PV modules in the world as well as in 2021. **China** produced 294.7 GW of PV modules in 2022 with 552 GW/year of production capacity. In 2022, the amount of PV modules exported from China were the highest recorded in history according to CPIA, and 153.6 GW of PV modules were shipped to overseas markets. As shown in Table 4.1, top five PV module manufacturers are Chinese companies.

As in 2021, the second largest PV module producing country in 2022 was **Vietnam** with 24.1 GW, a 47% increase from the previous year (16.4 GW), followed by **Malaysia** (10.8 GW) in the third position. In the first half of 2023, **China**'s PV module production was more than 220 GW (up more than 62% compared to the same period in 2022).

**FIGURE 4.5**: SHARE OF PV MODULE PRODUCTION IN 2022



SOURCE IEA PVPS, RTS CORPORATION

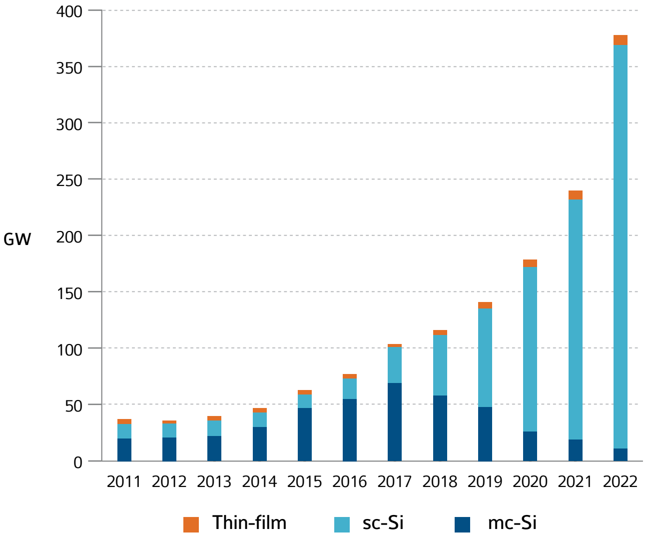
# THE UPSTREAM PV SECTOR / CONTINUED

In the **USA**, under its policy to safeguard domestic manufacturers from unfair trade practices with import duties, PV module production capacity has been increasing and is expected to significantly increase in 2023 as a result of incentives for production currently being implemented under the Inflation Reduction Act (IRA) signed into law in August 2022. According to the announcements made by manufacturers as a result of IRA, nearly 80 GW/year of PV module manufacturing facilities are planned to be newly installed in the next several years, of both c-Si and thin film technology, if all the announcements became reality. If the construction of a new PV module manufacturing factory by PLI is similarly realized in **India**, **India**'s PV module production capacity is expected to reach 30 GW/year by 2024 and about 70 GW/year by 2025. Plans of regional production of PV modules are becoming active in Europe as well. It is expected that, driven by the demand for lower carbon footprints, economic stimulation, and mitigation of risk to depend on specific production locations under the initiative by the European Union (EU), new manufacturing sites of PV modules will be increasingly established in Europe as well.

The PV module price stayed at high levels in 2022, as a continued trend from 2021, mainly due to higher polysilicon prices. In January 2022, average spot price of a sc-Si PV module (166 mm, 440-450 W) was 24.7 USD cents/W. It increased to 25 USD cents/W in June 2022 and further to 26 USD cents/W in and after July 2022. The price started dropping in September 2022, and dropped to 23.9 USD cents/W at the end of December 2022. Since February 2023, it has further dropped to 21 USD cents/W.

## SOLAR MODULE TECHNOLOGY

**FIGURE 4.6**: PV MODULE PRODUCTION PER TECHNOLOGY IN 2022



**SOURCE** IEA PVPS, RTS CORPORATION

In 2022, as shown in Figure 4.6, the share of c-Si PV module was 97.5%, a slight increase from 95.8% in 2021. Among c-Si PV technologies, the share of sc-Si PV further increased from 88% in 2021 to 94.6% in 2022. As mentioned in the chapter of wafer and cell, adoption of larger-sized solar cells increased. PV modules adopting half-cut c-Si solar cells are the mainstream, accounting for more than 90% of all the PV modules in 2022. PV modules with third-cut cells and further separated cells are manufactured as well. Shingled PV module technology (overlapping the edges of solar cells without ribbons) and seamless soldering technology were also adopted. In the **USA**, bifacial PV products are exempt from safeguard tariffs, and the share of bifacial products is increasing due to the widespread use of combinations of bifacial PV modules and trackers.

The share of thin-film silicon technologies slightly decreased from 3.4% to 2.5%. About 9.5 GW of thin-film PV modules were produced in 2022. As in 2021, the majority of the thin-film PV modules were CdTe PV modules produced by First Solar in the **USA**, **Malaysia**, and **Vietnam**. Other thin-film technologies produced in 2022 were CIGS with less than 500 MW and amorphous-silicon PV modules. Thin-film PV modules were mainly produced in **Malaysia**, **USA**, **Japan**, **Germany**, and **China**.

In several IEA PVPS member countries such as **China**, **Japan**, **South Korea**, **USA**, **Germany**, the **Netherlands** and **Sweden**, R&D efforts on CIGS, organic and perovskite thin-film PV modules 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 solar cells are becoming active. In **China**, Hangzhou Microquanta Semiconductor (**China**) announced in July 2022 that it had shipped 5 000 perovskite PV modules. Shenzhen Infinite Solar Energy Technology (**China**) successfully raised funds to build a pilot production line in 2022. GCL Optoelectronics (**China**) is currently operating at 100 MW/year (with a production capacity of 10 MW/year at the time of opening the facility). Hangzhou Microquanta Semiconductor announced that its mass-produced perovskite PV module "Microquanta Module-α" passed two certifications (one domestic and one foreign) with a full set of IEC61215 and IEC61730 stability tests. The company also announced that it has obtained the world's first capacity evaluation report for distributed power plants using perovskite solar cells.

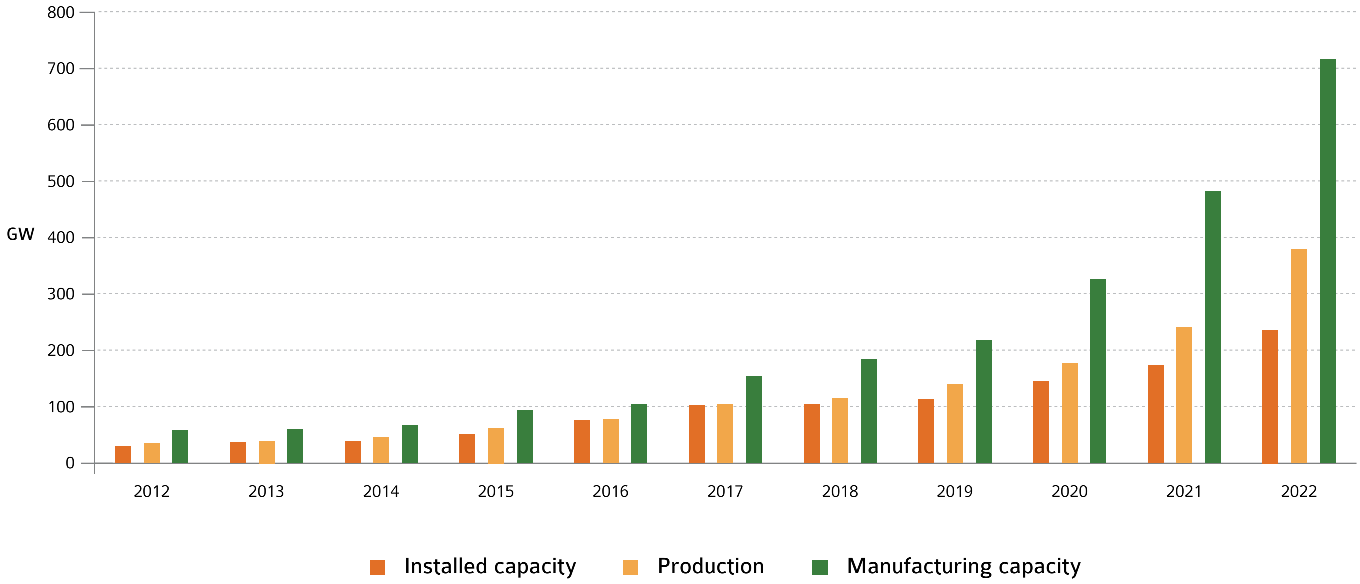
Outside **China**, Saule Technologies (**Poland**) will reportedly expand its production capacity of its flexible perovskite solar cell factory in 2023 to 720 000 m2/year. In the **UK**, PowerRoll began roll-to-roll pilot manufacturing in February 2022. In the **USA** several companies are investigating perovskite modules and tandems, including Swift Solar and Ascent Solar who are working separately on flexible PV modules. In **Japan**, companies such as Toshiba, Sekisui Chemical, Kaneka, Enecoat Technologies, and Aisin are working on R&D under the New Energy and Industrial Technology Development Organization (NEDO)'s R&D program with the aim of commercialization. The share of thin-film PV modules are expected to grow for specific applications for curved surfaces, window or skylights with light transmitting functions, applications requiring light-weight modules. The practical application of tandem technology using perovskite solar cells and c-Si solar or thin-film CdTe cells is also actively being carried out around the world. Oxford PV (**UK**) aimed to complete a perovskite/c-Si tandem solar cell production line with a production capacity of 100 MW/year in July 2021. While a number of initiatives have been announced, it remains to be seen whether perovskite solar cell technology will be able to capture a portion of the market share held by conventional c-Si and thin-film PV module technologies.

High efficiency multi-junction (MJ) PV cells/modules have been produced, mainly using III-V materials for space applications. R&D activities for high efficiency MJ PV have been active in the **USA**, Europe and **Japan**. R&D for tandem solar cell and modules using c-Si and MJ cells has also continued in these countries. Hydrogen synthesis using high efficiency cells is also studied and demonstrated. Application of CPV for agricultural PV is demonstrated as well. Demonstration of MJ PV for EVs is conducted in **Japan**.

# THE UPSTREAM PV SECTOR / CONTINUED

## PRODUCTION CAPACITY EVOLUTION

**FIGURE 4.7**: YEARLY PV INSTALLATION, MODULE PV PRODUCTION AND MODULE PRODUCTION CAPACITY 2012-2022 (GW)



**NOTE**: REVISED BASED ON CPIA DATA AND RTS SURVEY

**SOURCE** IEA PVPS, RTS CORPORATION

Figure 4.7 and Table 4.2 show the evolution of global annual PV installed capacity, PV module production amount and PV module production capacity. In 2022, production capacity increased to 717 GW/year from 483 GW/year in 2021. The progress of production capacity can be attributed not only to the establishment of new facilities but also to the improvement of conversion efficiency of solar cells and modules.

However, the production capacity figures include the capacities of aging facilities and idle facilities that are not competitive anymore: hence the real effective production capacity is assumed to be on the level of about 500 GW/year in 2022. The speed of capacity enhancement is faster than the market development so that the price level of PV modules is expected to be stabilized for the time being under the current circumstances where supply and demand of polysilicon has been eased.

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

| ACTUAL PRODUCTION | | | | PRODUCTION CAPACITIES | | | |
|---|---|---|---|---|---|---|---|
| YEAR | IEA PVPS COUNTRIES | OTHER COUNTRIES | TOTAL | YEAR | IEA PVPS COUNTRIES | OTHER COUNTRIES | EQUIPEMENT UTILISATION RATE |
| **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 | 39 869 | 55 394 | 5 100 | 60 494 | 66% |
| **2014** | 43 799 | 2 166 | 45 965 | 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** | 329 842 | 48 758 | 378 600 | 611 124 | 105 476 | 716 600 | 53% |

**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

## BALANCE OF SYSTEM COMPONENT MANUFACTURERS AND SUPPLIERS

Balance of system (BOS) component manufacturers and suppliers represent an important part of the PV value chain and BOS components are accounting for an increasing portion of the system cost as the PV module price is falling. Accordingly, the production of BOS products has become an important sector of the overall PV industry. Originally, the supply chain of PV inverters was affected by national codes and regulations so that domestic or regional manufacturers tended to dominate domestic or regional PV markets. However, with the growth of the Chinese market, dominance of Chinese products has continued in both utility-scale and distributed PV markets. According to CPIA and other sources, the global share of **China**-made inverters in 2022 was approximately 69.3%.

Generally, inverters are categorized into three types: central inverters, string inverters, and micro-inverters called MLPE (module level power electronics). In 2022, the share of central inverters used for large-scale utility or industrial applications was about 33% and the market share of string inverters used for residential and small to medium-scale commercial PV systems was 64%. The share of MLPEs remains low at about 1%, mainly for residential and small-scale commercial applications.

In 2022, many inverter manufacturers were impacted by their supply chains and were unable to shorten their lead times to pre-pandemic levels. Supply is expected to ease in 2023, but concerns remain about whether the supply and demand of key components such as IGBTs (insulated gate bipolar transistors) and chips will ease, and shipments continue to be delayed in some cases.

New grid codes require the active contribution of PV inverters to ensure grid management and grid protection. Grid forming, which has sophisticated control and interactive communications functions with digital technologies and responds to inertia force, is now being developed. Along with the growth of the distributed market, hybrid products that support power storage for residential and commercial use are increasing, and applications for EVs and virtual power plants (VPPs) are expanding. For self-consumption, functions to optimize self-consumption have been equipped, supported by an energy management solution combining energy storage systems and EVs with smart monitors. Application of AI and machine-learning for failure detection as well as optimization of electricity generation contributed to lowering the O&M cost.

In addition to conventional inverters mentioned above, the market of MLPE is growing in specific markets. Microinverters and DC optimizers (working on module level) are mainly adopted in the **USA** residential market to respond to rapid shutdown requirement imposed by the National Electricity Code (NEC). MLPE can help achieve a higher output for PV systems which are affected by shading and a more efficient rapid shutdown can be realized in case of fire. Such requirement was adopted first in the **USA** then **Thailand** and the **Philippines**. **China** is also considering introducing rapid shutdown requirements so that the market size for MLPE is expected to grow in the future.

Regarding the plans of establishing PV manufacturing bases in the **USA** as mentioned above, the production capacity of inverters in the **USA** is expected to increase. Under the IRA, incentives are also provided for inverter manufacturing, depending upon inverter type, and the IRA's incentives are expected to increase demand for **USA**-made inverters as there is a 30% investment tax credit (ITC) plus a 10% bonus for projects meeting domestic content requirements.

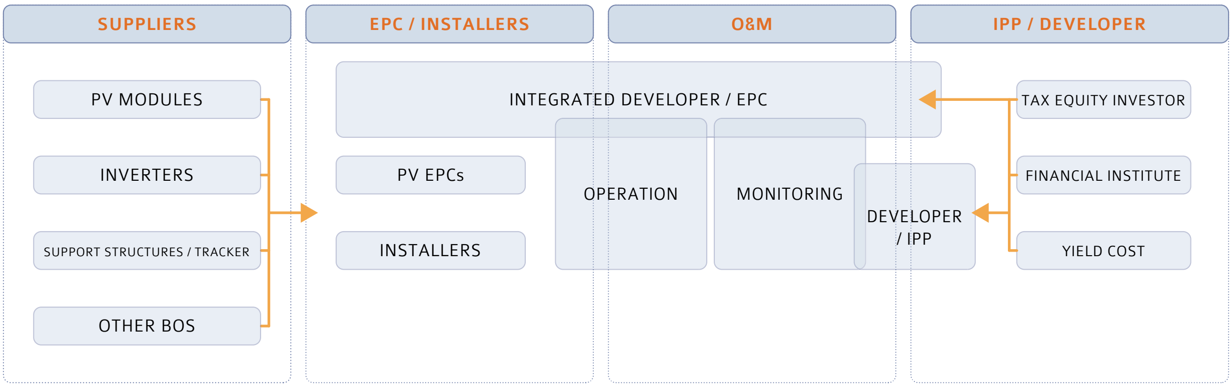
Among other BOS segments, the market of single axis tracker has been growing. The market size of 2022 is assumed to have reached around 46 GW. The largest tracker market is the **USA**, where about 70% of the utility-scale projects are built with single axis trackers. Aside from the **USA**, the market for PV trackers is expanding to such major markets as **China**, **India**, South America, **South Africa**, **Saudi Arabia** and the **United Arab Emirates** (**UAE**). The **USA** manufacturers account for more than 50% of the global single axis tracker production as their domestic market is large, but single axis trackers are also produced in demand areas such as **China** and Europe. As for inverters, in the **USA**, the production capacity of trackers is expected to increase as IRA tax credits provide both an incentive for the production of tracker components and a bonus for meeting domestic content requirements for solar projects. Besides utility-scale applications, trackers used for agriPV projects are developed and commercialized with specific designs to share solar energy with crops.

# THE DOWNSTREAM PV SECTOR

In the PV industry, an overview of the downstream sector is shown in Figure 4.8 (example of utility-scale projects). PV developers have been active in the countries where power purchase agreements (PPAs) are guaranteed under auctions, and where the Feed-in Tariff (FIT) program and other mechanisms are implemented. While some developers sell PV power plants to Independent Power Producers (IPPs) and investors, other developers own PV power plants as their own assets. Companies providing engineering, procurement and construction of PV systems (mainly utility-scale applications, but larger commercial or industrial applications also fall into this category) are called EPCs (Engineering, procurement, and construction). EPCs include pure-player companies and general construction companies offering services for installing PV systems. Integrated PV developers sometimes conduct EPC and operation and maintenance (O&M) services themselves. Some companies develop PV power plants and own them, while others provide EPC and sell the PV power plants to IPPs. Generally, utility-scale projects are owned by IPPs (together with equity investors), who sell the power to utilities under long-term PPAs. Equity investors or other financial institutes also play an important role for PV project development as equity or loan providers.

Companies doing business in the downstream sector have various origins: subsidiaries of electric utilities, subsidiaries of PV module manufacturers, companies involved in the conventional energy or oil-related energy business. Major PV project developers are accelerating their overseas business deployment and are active in business deployment in markets such as Africa, the Middle East, ASEAN region and Latin America. The number of project developers active in the international business is increasing. It should be also noted that several vertically integrated companies are present in the downstream sector. These companies produce PV modules or polysilicon, develop PV projects and provide EPC and O&M services. c-Si PV module manufacturers such as JinkoSolar (China), Trina Solar (China), Canadian Solar (Canada), and Hanwha Solutions (South Korea) are also active in the downstream sector. While these companies exist, First Solar (USA) announced that it would withdraw from project development and O&M business and focus on the manufacture of PV modules. Oil and other major energy companies also entered into the renewable energy market.

**FIGURE 4.8**: OVERVIEW OF DOWNSTREAM SECTOR (UTILITY PV APPLICATION)



SOURCE IEA PVPS & OTHERS.

# THE DOWNSTREAM PV SECTOR / CONTINUED

European companies are most active in this field. For example, BP (**UK**) is shifting from an integrated oil company (IOC) to an integrated energy company (IEC). TotalEnergies (**France**) is focusing on gas and low carbon electricity and develops PV projects globally. Shell (**UK/Netherlands**) announced its strategy to accelerate its transformation into a provider of net-zero emissions energy products and services. In addition to advancing renewable energy projects, these companies are also investing in storage batteries and promoting green hydrogen projects.

In the downstream sector, business models have been changing with the increased demand for renewable electricity from users seeking to procure 100% renewable power for their business operations. Especially in the countries where the electricity market is liberalized, there are some cases where IPPs sell PV electricity directly to the corporate electricity consumers. These contracts are called Corporate PPA (CPPA). In 2022, demand for CPPAs increased around the world as energy prices soared due to concerns over energy security triggered by Russia's invasion of **Ukraine**. Bloomberg NEF (BNEF) reported that global CPPAs signed increased from 31.1 GW in 2021 to 36.7 GW in 2022. While renewable energy procurement via CPPAs by IT companies such as GAFA has been attracting attention, such procurement by mining companies is also active in countries such as **Australia**, **Chile** and **Brazil**. In Europe in 2022, the contracted capacity increased as PPA contract prices rose and more IPPs chose to transact power in the wholesale electricity market without signing PPAs. Additionally, with the decrease of the PV module price, lower contracted prices have been reported in 2023 and the demand for CPPAs is expected to increase hereafter.

In the segment of distributed PV systems for residential, commercial and industrial applications, demand for distributed PV is increasing for self-consumption and resilience. The Russian invasion of **Ukraine** and increasing climate challenges including heat waves, hurricanes, and polar vortices also raised the demand for distributed applications. In this segment, companies also provide on-site PPAs. In addition to these, obligation to install PV systems on new houses or buildings is adopted on national and regional levels (see Chapter 3). These mandatory measures and tighter energy efficiency codes also will drive the distributed PV market. There are some cases where the PPA model is utilized for introducing PV systems for residential, commercial and industrial applications.

# five

# SOCIETAL IMPLICATIONS OF PV AND ACCEPTANCE

PV is bringing profound changes to modern society, and positive impacts to economies, societies, and the environment, and has become a pillar of the energy transition and its path to sustainability and a more equitable world.

Due to the nature of the energy transformation, the acceptance of change is an essential element of the success of this revolution: 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. An understanding of these social aspects related to the development of PV is becoming essential.

Around the world, as penetration rates increase and PV becomes more visible, both on buildings and in landscapes, 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.

This chapter aims at providing key elements that can be used to promote a larger acceptance of PV development while highlighting essential aspects.

## ACCEPTANCE OF PV DEPLOYMENT

Acceptance can be defined as the willingness of stakeholders to approve, support, and engage themselves in the energy revolution. 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.

The first major drop in acceptability came on the heels of the boom growth in Spain in 2007-2008, when 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. Many other countries that stepped into the FiT policies experienced a major market development followed by a rapid halt. In most cases, the reason was clear: traditional utilities felt threatened, unable to jump fast into this rapidly developing business and pushed poorly informed authorities to put the brakes on PV development. While the image of PV was positive, it soon became polluted by the perception of extravagant profits, dramatic impact on electricity prices or quality issues.

# ACCEPTANCE OF PV DEPLOYMENT / CONTINUED

In the past, these subjects were used in some countries by PV opponents to discredit the PV sector – opponents generally coming from traditional energy sectors, governments or political parties. The EU was the epicentre of PV development until 2011-2012, and this happened across a number of European countries including **Spain**, **France**, **Belgium**, **Czech Republic**, **Greece**, **Bulgaria** and **Romania**. Riding on the environmental advantages of PV, the PV community somehow forgot the need for a broad social acceptance and was unable to work with governments to create healthy dialogue. In some countries (**Belgium** for instance), 15 years later, PV still suffers from a poor image and frightens policymakers.

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...)

Whilst these issues are particularly present in European and North American markets, many markets have not yet reached critical mass levels for these issues to emerge. Initiating factors seem to include profitable but costly to the state feed in tariffs, high penetration rates and accelerated development of ground mounted systems, and without one or more of these, opposition seems to be low (**Sweden**, for example). For those where they are present, the PV sector, and in some cases PV sector bodies, 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.

## 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 revolves around the legal and regulatory framework. It resonates with concerns related to financial burdens, jobs, industry and local content. In multiple countries (**Turkïye**, **Morocco**, **India**), some policy makers were putting a hold on PV development until it was coupled with local value creation. In **France**, indirect local content requirement (based on an evaluation of module carbon footprints) have been used in tenders for years. Higher acceptance levels could be achieved by demonstrating the added value of PV in terms of job creation, revenue generation, economy and activity development, which could positively influence regions with, for example, industrial decline. Socio-political acceptance is often lagging behind community acceptance in the early stages of PV development in a country.

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, 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, lobbyist ...). Higher acceptance levels could be achieved by transferring value, part of the decision process or at least discussions to the citizens and local stakeholders at large. In **Spain**, distributed PV with sizes below 5 MW can participate in tenders provided that they respect certain conditions (securing local (<60 km) partners, demonstrating proximity to consumption centres) aiming at increasing PV acceptance and in tenders in **France**, bonus' are given when similar measures are taken. In general, the target is to overcome ignorance and misconception (e.g., about the land surface that is actually needed to meet the targets, the rigour of environmental impact studies and the financial flows) and increase trust that local community concerns have been heard.

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.

## INVOLVEMENT

The involvement of stakeholders in the energy transformation is often considered as a way to ease into acceptance and accelerate deployment. Stakeholders run across the value chain, from research down to permitting, construction and use – with stakeholder involvement important in some keys areas such as permitting, grid connection and investment. Tools to increase involvement include self-consumption (encouraging all citizens to become generators), energy communities (where collective and citizen-driven partnerships invest in and/or manage energy tools such as generation or local energy sales companies) and collective ownership, public consultations in permitting procedures, open participation in the elaboration of climate and energy transition policies and targets and education in the energy industry.

In **Austria**, trials have been undertaken to involve citizens in energy planning and investment; in **France**, the government co-finances the promotion of citizen investment and ran an information campaign to increase participation in citizen investment, whilst creating a framework to increase self-consumption; in the **USA**, the R-STEP (the Renewable Energy Siting through Technical Engagement and Planning) program will support the creation and/or expansion of state-based programs that improve renewable energy planning and siting processes for local communities via collaboration. 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.

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 population significantly increases the adoption of distributed energy sources.
- 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.

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 MITIGATION

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

Global energy related CO2eq emissions increased to 36 800 Mt[1] in 2022, just 0.9% more than 2021, much lower than expected considering the shift from gas to coal in some countries. 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 436 g CO2/kWh[2] in 2022 whereas for 1 kWh produced by PV the CO2 emitted, taken on a life cycle basis, can be as low as 15 g depending on technology and irradiation conditions (data from IEA PVPS Task 12 on sustainability and the databases made available by the groups' researchers).

The total CO2 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 2022 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. 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 country-specific life cycle CO2 emission factors (g CO2/kWh) of both PV electricity and grid mix electricity are taken from the IEA PVPS Task 12 databases; whilst more recent, updated values for grid mixes are available for individual countries and could improve single country results, the perimeter and methodology for these sources is not always known and could lead to more significant errors or reduce the ability to compare between countries For these reasons, this report continues to use the Task 12 database.

**$CO_2$ avoided**

1 336 MT $CO_{2eq}$

Using this methodology, calculations show that the PV installed capacity today avoids up to 1 336 million tonnes of CO2eq annually. Thus, it avoids more than 3.5% 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** and **India**.

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[1] https://www.iea.org/reports/co2-emissions-in-2022

[2] https://ember-climate.org/insights/research/global-electricity-review-2023/

# CLIMATE CHANGE MITIGATION / CONTINUED

Figure 5.1 gives a view of the avoided CO2 emissions in the first 30 countries in ranking of avoided CO2 emissions, who represent in total around 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 CO2 the power mix in a country emits, the more positively PV installations will contribute to avoiding emissions.

**FIGURE 5.1**: $CO_2$ EMISSIONS AVOIDED BY PV

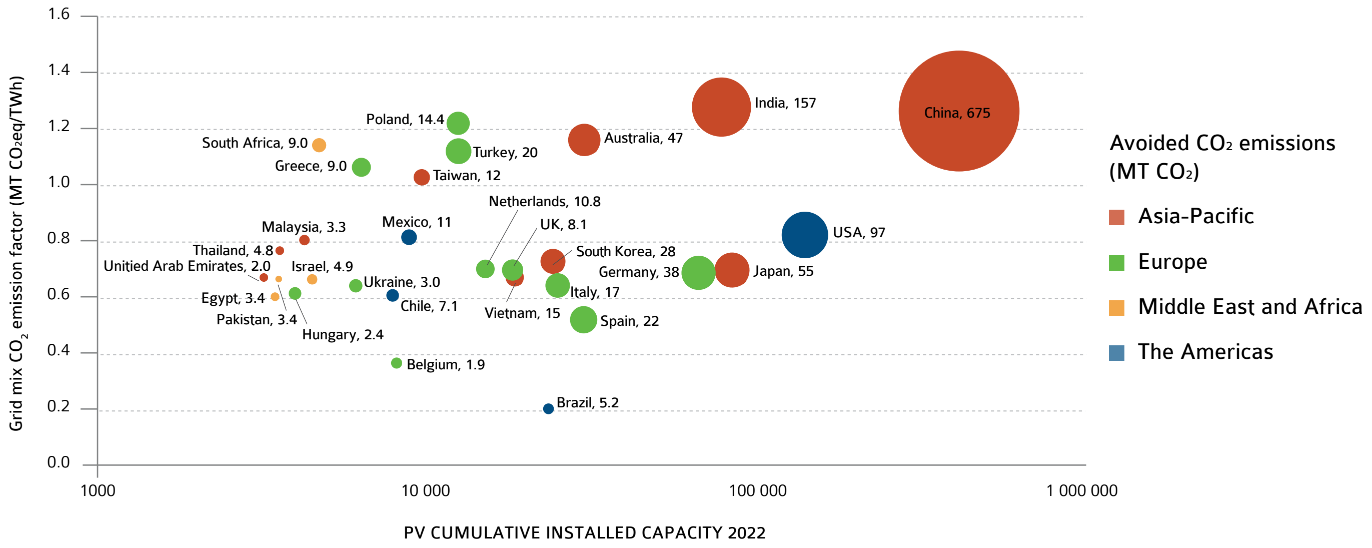


**FIGURE 5.2A**: AVOIDED $CO_2$ EMISSIONS AS PERCENTAGE OF ELECTRICITY SECTOR TOTAL EMISSIONS

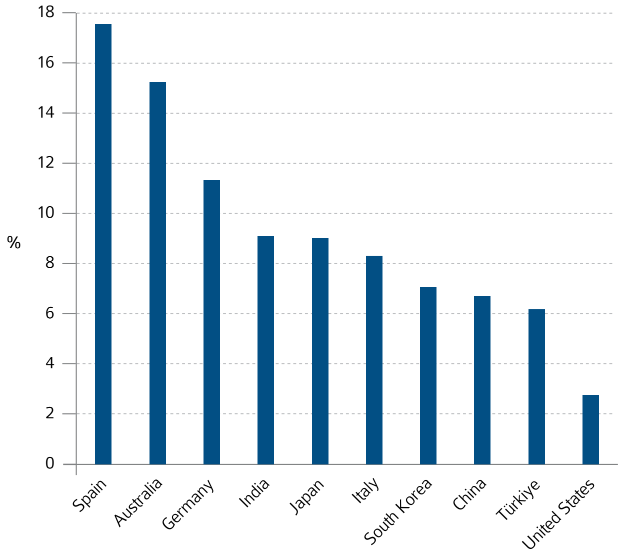
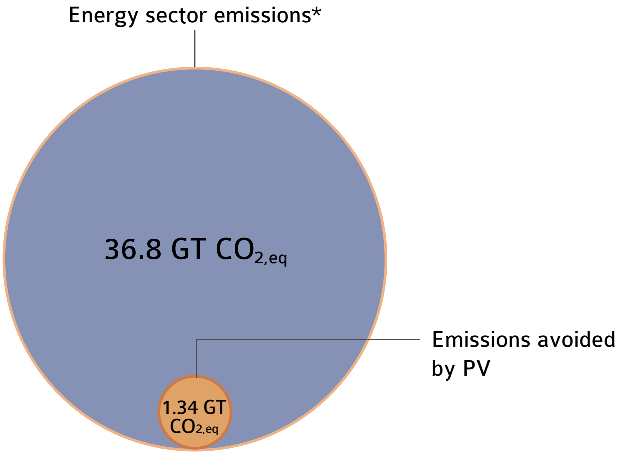


**FIGURE 5.2B**: AVOIDED $CO_2$ EMISSIONS AS PERCENTAGE OF ENERGY SECTOR TOTAL EMISSIONS



*Energy related $CO_2$ emissions from fuel combustion

SOURCE IEA PVPS & OTHERS

## VALUE FOR THE ECONOMY

The turnover of the PV sector in 2022 amounted to around 237 billion USD. This number has been calculated based on the size of the PV market (annual installations and cumulative capacities) and the average price value for installation and Operations & Maintenance (O&M) specific to the different market segments and countries.

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 10 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). The real value of O&M is probably higher than this, above 12 billion USD per year, if all operations could be included.

According to our estimates, in parallel to the growth of the annual market, the global business value of PV installations has increased by around 25% and so did the global value for O&M. This is roughly on par with the 19% increase of 2021, and it is still important to note that this value increased less than annual new installed volumes increased (35%) – overall prices in many markets decreased, even if some markets remained high over the first half of 2022. It is worth noting that the O&M value is bound to grow further, powered by increasing volumes of centralised systems, aging plants and repowering operations.

The choice was made to assess the value of the PV sector for the economy based on the number 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 distributed 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.

**Turnover PV**

237 Billion USD

**O&M**

10 Billion USD

**Global business value**

+ 25% in 2022

### CONTRIBUTION TO THE GDP

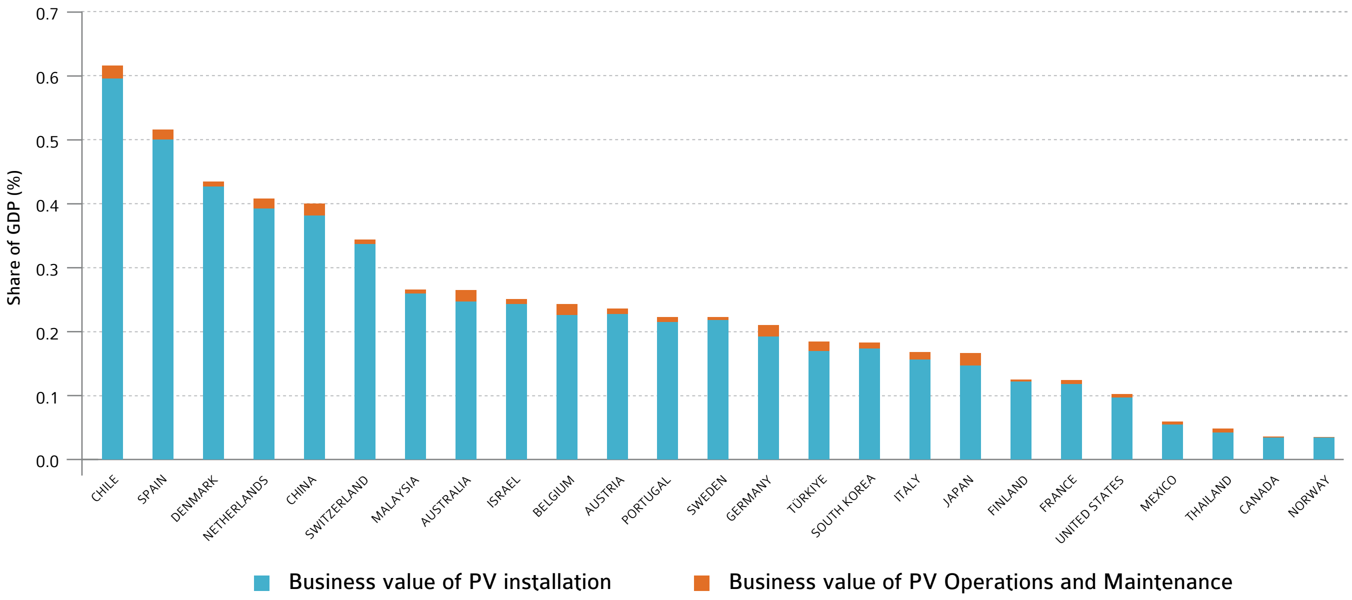
Figure 5.3 shows the estimated business value of the PV sector in IEA PVPS reporting countries as compared to their national GDPs. These values were determined based on the internal PV markets in each country, as described above, and hence they do not take imports or exports into account. Some countries 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.

As shown by Figure 5.3, the business value of PV compared to GDP is growing as national market sizes increase – **Chile**, **Spain** and **Denmark** all hit above 0.4% of GDP, whilst the **Netherlands**, **China** and **Switzerland** are above 0.3%. On a global scale, PV business value represents around 0.25% of the GDP compared to around 2.9% for energy investments.

Whilst investments in PV, and hence the energy transition, are increasing, they are still a long way from significant; multiplying markets tenfold would still leave outlay at a relatively low level. There is room in national and international expenditure to go further – for example, 105 billion USD was invested in the coal supply chain globally in 2021.

# VALUE FOR THE ECONOMY / CONTINUED

## FIGURE 5.3: BUSINESS VALUE OF THE PV MARKET IN 2022



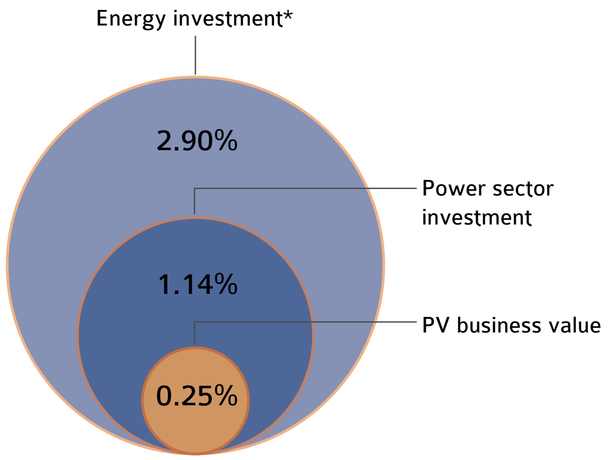
SOURCE IEA PVPS & OTHERS

## TABLE 5.1: TOP 10 RANKING OF PV BUSINESS VALUES

| RANK | COUNTRY | BILLION US$ |
|---|---|---|
| 1 | CHINA | 72 |
| 2 | UNITED STATES | 26 |
| 3 | GERMANY | 9 |
| 4 | SPAIN | 7.2 |
| 5 | JAPAN | 7.1 |
| 6 | AUSTRALIA | 4.5 |
| 7 | NETHERLANDS | 4.0 |
| 8 | FRANCE | 3.5 |
| 9 | ITALY | 3.4 |
| 10 | SOUTH KOREA | 3.0 |

SOURCE IEA PVPS & OTHERS

## FIGURE 5.4: CONTRIBUTION TO GLOBAL GDP OF PV BUSINESS VALUE AND ENERGY SECTOR INVESTMENTS



*Investment in the power sector, fuel supply and end-use & efficiency

SOURCE IEA PVPS & OTHERS

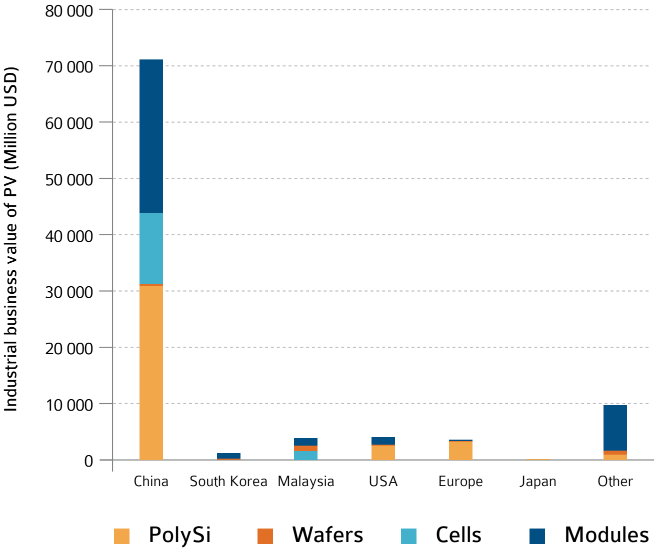
## INDUSTRIAL VALUE OF PV

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 by member countries. We consider that equipment and materials are included in this calculated value. BoS, including inverters are not considered here.

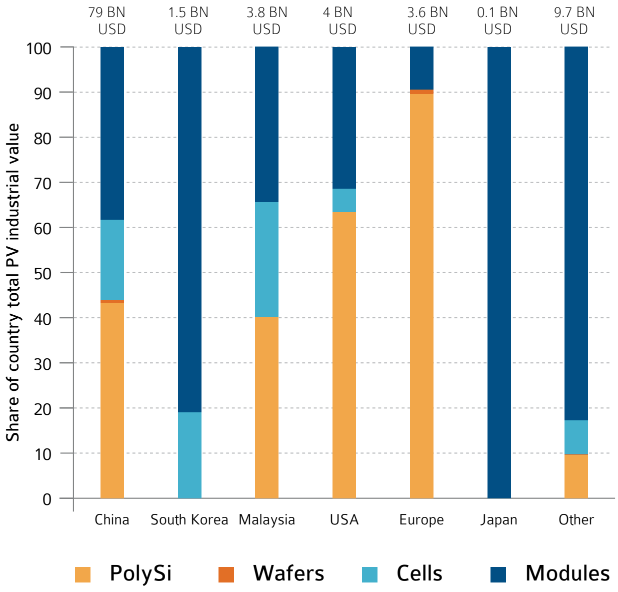
The estimated global industrial value of PV was approximately 93.6 billion USD in 2022. Figure 5.5A, 5.5 B and 5.5C show for major PV manufacturing countries the estimated contribution of each step of the value chain in the PV industrial value for each country in absolute and relative terms as well as the comparison of this value to their GDP.

**FIGURE 5.5A**: ABSOLUTE PV INDUSTRIAL BUSINESS VALUE IN 2022



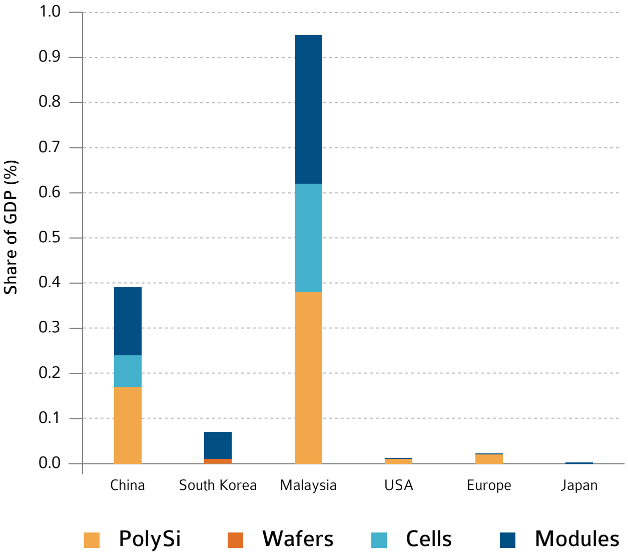
SOURCE IEA PVPS & OTHERS

**FIGURE 5.5B**: PV INDUSTRIAL BUSINESS VALUE ALONG THE VALUE CHAIN IN 2022



SOURCE IEA PVPS & OTHERS

**FIGURE 5.5C**: PV INDUSTRIAL BUSINESS VALUE AS SHARE OF GDP IN 2022



SOURCE IEA PVPS & OTHERS

## VALUE FOR THE ECONOMY / CONTINUED

**China** is by far the predominant manufacturing country in all steps of the PV value chain, shows an approximate share of 0.4% of its GDP (up 0.1% since 2021) 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**, exceeding 0.9%. **South Korea** shows an approximate 0.07% share, while remaining countries do not exceed 0.02%. With projects to relocalise PV industries in the **USA** and Europe, this may change in the coming years.

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.

### SOCIAL IMPACTS - EMPLOYMENT IN PV

Figure 5.6 gives an overview of the total direct jobs in IEA PVPS countries and **India**. 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.

The methodology that was used started from the data provided by reporting countries on the upstream (industrial) and downstream (installation and O&M) job numbers, which were then extrapolated to other markets depending on their respective work market specifics. A distinction was therefore made between countries in developed economies having a costly, low intensity work market and the emerging economies with an affordable work force. Manufacturing numbers are based on industry reports and additional sources and split according to the same methodology. When numbers differed from official job numbers, official numbers were always considered. Installation numbers are always an approximation.

This report estimates that the PV sector employed an estimated 5.8 million people globally at the end of 2022. An estimated 1.9 million were employed in the upstream part, including materials and equipment, while 3.9 million were active in the downstream part, including O&M.

**PV sector employed an estimated**

5.8 million people in 2022

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 4.1 million jobs in 2022, which corresponds to a significantly higher job intensity than almost anywhere else. Lower by one order of magnitude, **India** and the **USA** follow, with respectively 450 000 FTE and 260 000 FTE estimated. The European Union has about 330 000 jobs, followed by **Vietnam** at around 130 000 FTE then Japan at around 90 000 FTE. Generally, in good correlation with the market evolutions, PV employment expanded where the market developed: installation jobs are often temporary ones, depending on the market dynamics.

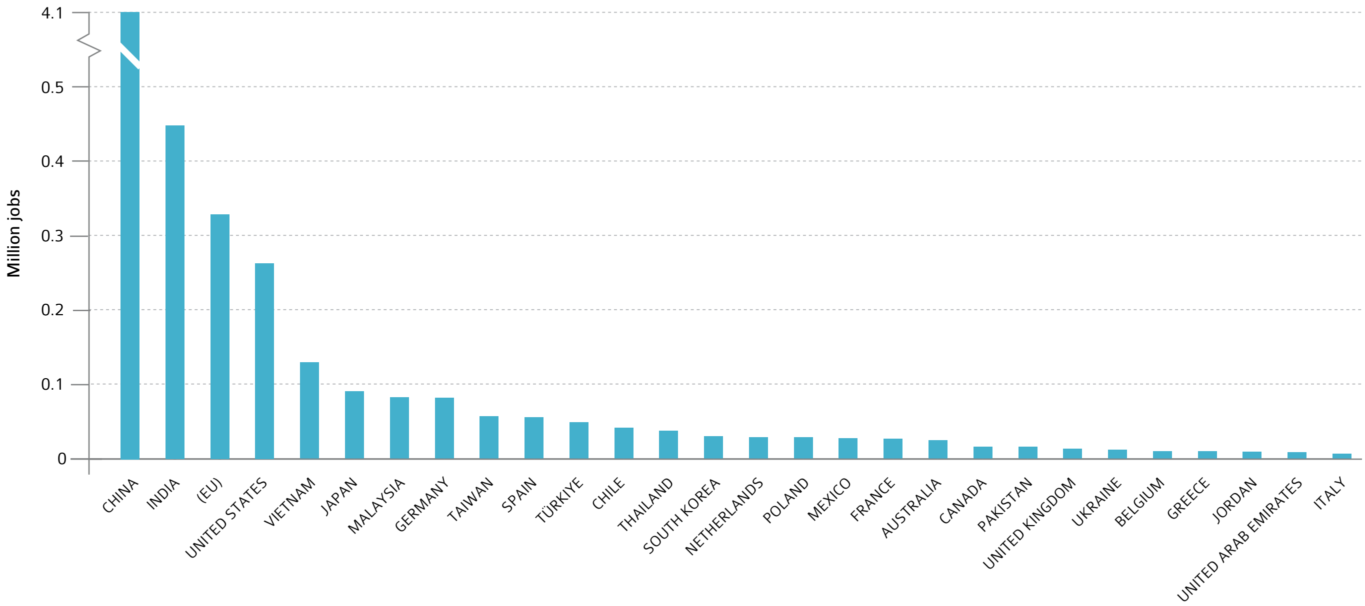
Employment dynamics in the PV sector are evolving in line with the changes in the PV markets and industry. PV labour place trends reflect the status of the PV industry landscape development and how the supply chain is becoming more globalised and geographically differentiated – although efforts in different countries for reindustrialisation may change this in the coming years.

When specifically focusing on development and installation activities, more labour intensive than manufacturing, on average the job intensity is approximately 15 FTE per MW. However, these numbers vary considerably from one country to another and additionally from one market segment to another. Small-scale PV generates more jobs than utility-scale PV in general, and with widely differing markets the intensity can be very different – for example, in **Spain** the market in 2022 was 40% centralised PV, and hence likely to generate less jobs per MW than in **Germany** where the markets had 75% of new capacity in distributed PV, with a higher job intensity than centralised PV.

O&M generates many manual jobs while the entire PV value chain creates good quality jobs, from research centres to manufacturing. In summary, the upstream part generates around 5 FTE per MW produced while the downstream part generates around 15 FTE per MW installed.

With an estimated total of 5.8 million jobs in the solar PV sector worldwide in 2022, PV employs more than one third of the total renewable energy workforce and remains number one in the employment ranking of the global renewable energy sector.

**FIGURE 5.6**: GLOBAL EMPLOYMENT IN PV PER COUNTRY



**SOURCE** IEA PVPS & OTHERS

## LOCAL MANUFACTURING

The emergence of PV as a mainstream technology woke up appetites for local manufacturing and job creation at all levels of the value chain. Looking at just IEA PVPS member countries, several countries have pushed through different schemes for local manufacturing in recent years, namely **Canada**, **Türkiye** and the **USA** whilst others have at least initiated studies in this direction (**France**, **Australia**). Elsewhere, some countries have succeeded in bringing manufacturers to produce PV components in their country, for example in **Malaysia**, **Vietnam**, and **Thailand**. **South Africa** initiated local measures for partnerships with Chinese manufactures but have not yet been able to follow through. Other countries, such as **Chile** and **Saudia Arabia** seem to be thinking about it.

With the disruptions in the PV value chain caused by the pandemic and the increased cost of shipment, the question of local manufacturing gained traction in 2021 and remained in 2022, despite shipping costs returning to pre-pandemic levels early in the year. While local production requires investments, skills and, ideally a stable local market, this perspective is facing a significantly higher interest from policymakers. Countries such as **India** and the **USA**, to name a few, are pushing hard to develop a local industry and increase their partial independence. All these projects and new manufacturing capacities require skilled workforces – and it is increasingly becoming a potential barrier; for example, Europe has identified the need to train at least 100 000 new people over 3 years for the PV industry.

# VALUE FOR THE ECONOMY / CONTINUED

## IMPACT ON ELECTRICITY BILLS

In the past many analysts and opposants have discussed the impact of PV support mechanisms on end-user electricity bills, however, in the past two years, three different factors have changed the general discourse on this subject in many countries.

Firstly, PV is reimbursing its support mechanisms: the impact of the increase in gas prices resulting from sanctions due to the war in Ukraine have 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 - in France, support mechanisms for solar raised 724 million euros (761 million USD) for the government that helped compensate and contain electricity prices for consumers.

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. Numerous studies in various countries have shown that PV reduces wholesale market prices for electricity at the time of generation – and this has never been more obvious than in the past few years with high spot prices amidst gas supply and price upheaval due to the war in Ukraine. In some cases, negative prices have been seen at times of high PV penetration, even if this isn't the sole cause. The savings for electricity consumers and the society, in general, is difficult to calculate but most studies conclude on significant savings and additional, 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 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 are supplying services on the market at competitive costs, whilst distributed batteries are reducing service loads on turbine generation. In the USA, solar power plants across several different states and extreme weather events have been key generators during crises.

However, much remains to be done to explain carefully the advantages of PV in reducing the energy cost of end-consumers, and more so for those without PV plants and counter false or misleading statements that reduce the confidence of the population in the energy transformation.

## PV FOR SOCIAL POLICIES

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 produced, PV entails additional positive implications on the social level if leveraged with appropriate policies.

As shown through the off-grid PV market development in Africa and Asia (see Chapter 2), 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 deserves a significant attention for electrification.

In an increasing number of countries with stable electricity networks and close to total electrification, programs are or have been established to assist low-income families to install grid connected solar, either through means tested rebates, loans or gifts from state agencies or private organisation (the USA at the national, state, and local levels, Australia, UK). Alternatively, the European push for facilitating 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 high electricity prices experienced across many countries in the past 2 years, self-consumption of increasingly cheap solar is more and more often seen as the best solution to maintaining electricity bill affordability.

Solar offers opportunities for social programs, and especially to fight energy poverty, which has not been widely used yet. While the reputation of PV, especially in the European countries that started to fund its development, is one of a costly energy source this is less and less the case. The energy crisis of 2022 has increased the competitiveness of PV to the extent that it could reduce the electricity bill of families, municipalities and companies, with or without a suitable roof, using the possibilities offered by delocalized (or virtual) self-consumption.

Some more specific examples of energy poverty programs involving solar include:

- In **Malaysia**, rural electrification is still a priority of the government, with a projected 100% electrification rate by 2025. Rural electrification is done together with utilities as a form of public-private partnership. In remote Sarawak, the Sarawak Alternative Rural Electrification Scheme (SARES) has electrified almost 5 000 households in 192 villages since its launch in 2 016 and has received regional recognition in 2019. Solar PV and hybrid systems are often used in this scheme, as well as micro hydro-technologies.
- In **South Korea**, in Seoul, with the financial aid from Seoul Metropolitan government, a non-profit organization, Energy Peace Foundation, and Solar Terrace company installed 30 kW mini-PV systems for 100 energy-vulnerable households (300 W/household). This type of mini-PV installations is becoming popular in **South Korea** to reduce the electricity bill burden during the summer.
- In **Italy**, the Municipality of Porto Torres (Sardinia Region), with the collaboration of the energy services operator, introduced in 2017 an energy income project. The municipality allocated public resources to purchase PV systems, sold on loan to families in energy poverty conditions, to allow them to benefit from PV self-consumption and thus reduce their energy bills. The revenues of the net-billing feed a public fund, in order to finance the maintenance of the plants or possibly the purchase of other plants for other families. The scheme has been replicated in other municipalities, and an energy poverty observatory has been set up.
- In **Australia**, a number of measures were announced by State Governments in 2020 and have been maintained in 2022 going from interest free loans to rebates (subsidy of up to 50% of the total cost) or even complete subsidies (Solar for Low Income Households for systems with an installed capacity up to 3 kW). Additional measures tackling rural electrification include a budget to support feasibility studies looking at microgrid technologies to replace, upgrade or supplement existing electricity supply and to finance the deployment of PV to reduce the use of diesel.
- In **France**, rural electrification is addressed in overseas territories and isolated alpine areas through budgets available for off-grid electricity production (1 MEUR budget in 2022), electric vehicle charging points, or grid-connection financing, whilst the widespread availability of micro PV kits (1 or 2 modules) is leading to small investments by many low income families.
- In the **USA**, the Inflation Reduction Act (IRA) contained 145 million USD in grants, 18 billion USD in loans, and carve-outs within the low-income bonus to the Investment Tax Credit for Tribal solar deployment to address disparity of electricity access for indigenous communities. The IRA also contained significant incentives for rural electrification, as well as measures targeted towards energy access for low-income communities, historically marginalized communities, and communities with higher rates of unemployment as a result of the energy transition.

## AESTHETICS AND LANDSCAPE

The energy transition requires the integration of large-scale ground mounted plants and distributed systems on rooftops across the world. More and more areas mandate significant penetration rates, in turn meaning PV will be visible to all in everyday life. However, very often landscape preservation issues are already a barrier to the large-scale implementation of photovoltaics in natural environments, as well as heritage in built environments – and social acceptance of the transformation and modernization of landscapes is in general low. In order to support the diffusion of photovoltaics this condition requires a paradigm shift to an enlarged design vision that includes not only technical, engineering considerations, but also landscape design ones.

Building a bridge between the large-scale deployment of photovoltaics and landscape design, paving the way to the design of sustainable, beautiful photovoltaic landscapes is not optional anymore. Integrated photovoltaic solutions have a big potential in terms of penetration of photovoltaics, as in general integration is a tool for diffusing new technologies into conservative environments.

Among the existing integrated solutions, "agrivoltaics" offer a solution to addressing concerns about energy vs. agricultural land use, as it maximizes land use by generating both energy and food simultaneously. At the same time these systems offer a possibility for experimenting with a varied set of solutions, which can be adapted to different landscape features. In the built environment, BIPV products such as coloured roof tiles or facades are another tool that can improve the visual acceptability of PV, although their costs bring new barriers.

# 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 later. A large disparity in useful lifetime is observed between distributed and centralised applications, with shorter useful lifetimes observed in centralised systems, mostly driven by economic considerations. 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 re-use and recycle minimum requirements, which are expressed in percentage by mass.

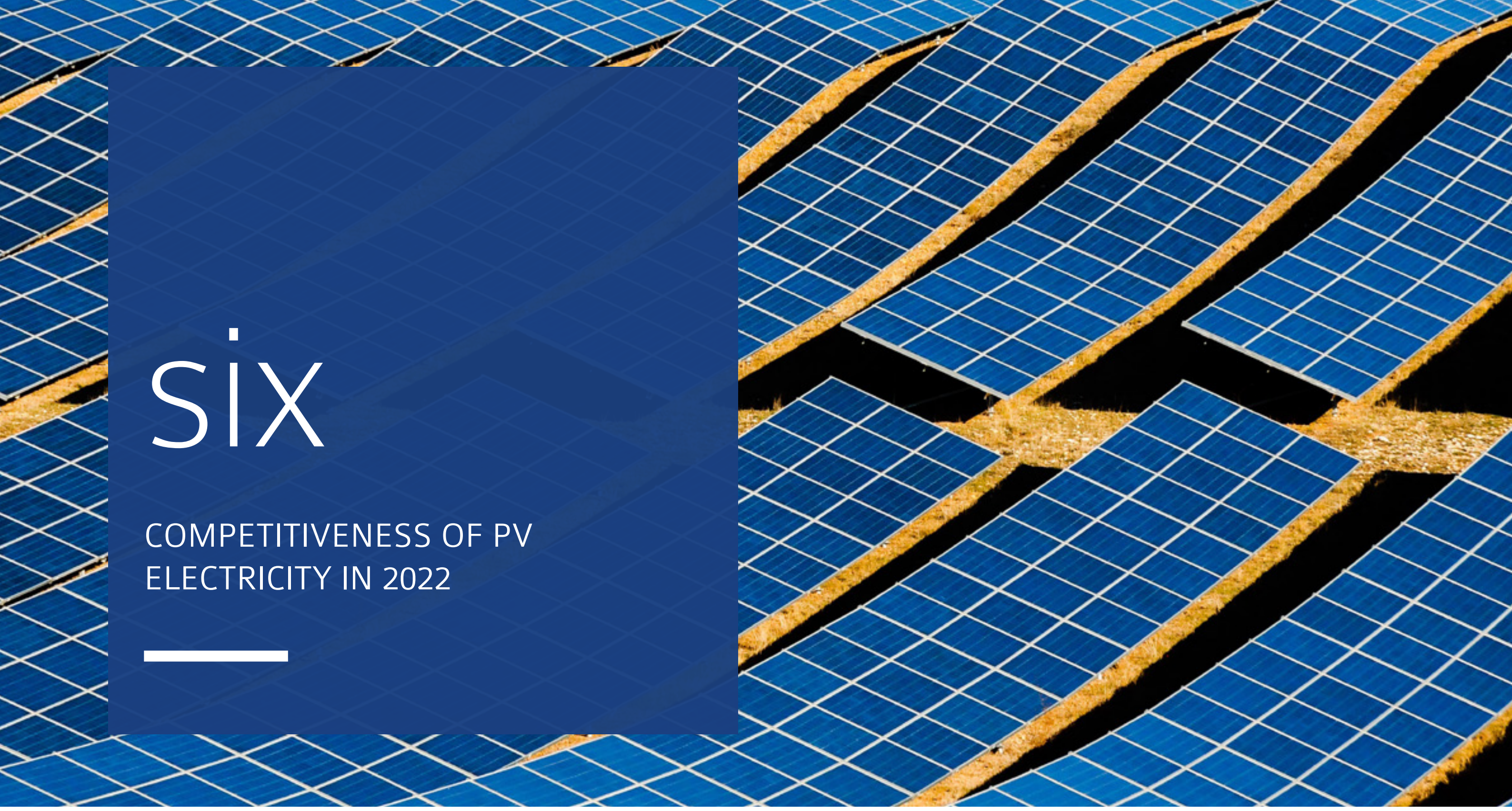
Recycling requirements are currently typically achieved through mechanical processes which rely on:

1. 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 recycling 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 national working group is assessing industry-led and co-regulatory options and the expected flow-on regulatory and economic impacts. In **Japan**, from July 2022, setting aside of future cost of EoL PV systems became compulsory for solar power generation facilities with more than 10kW 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** there are over 20 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 2022

**The rapid price decline that PV experienced in the past 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 depends on 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.

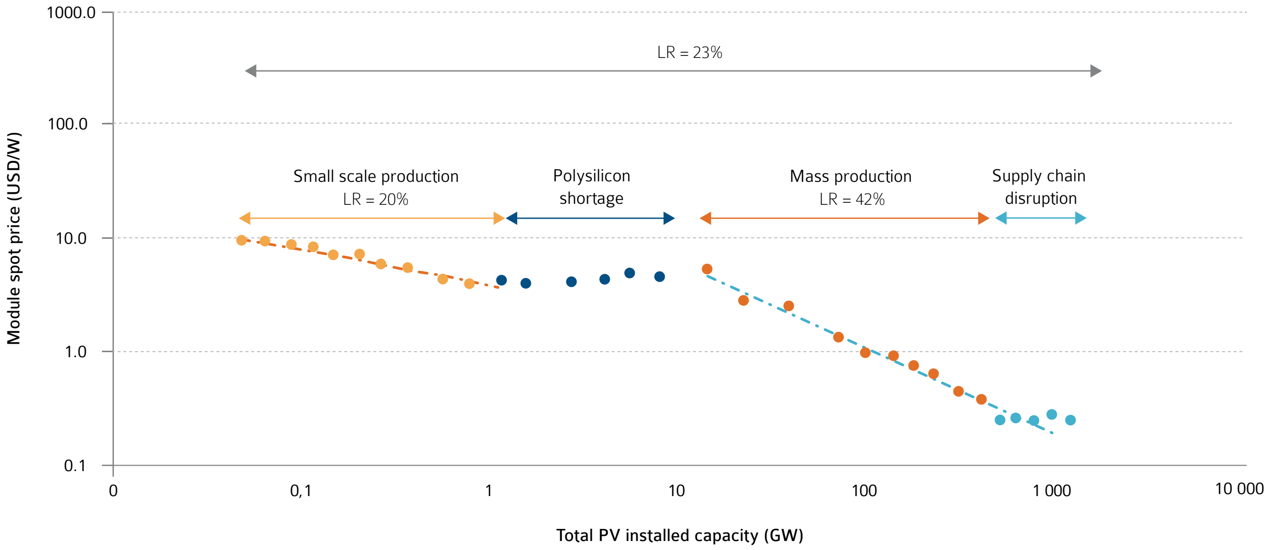
The question of competitiveness should always be contemplated in the context of a market environment created for conventional technologies and sometimes distorted by historical or existing incentives. The fast development of nuclear in some countries in the last 40 years is a perfect example of policy-driven 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. Here we will look at the key elements driving the competitiveness of PV solutions.

## MODULE PRICES

The initial 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 18% 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 continues to 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 led to an impressive 42% learning rate over the last decade.

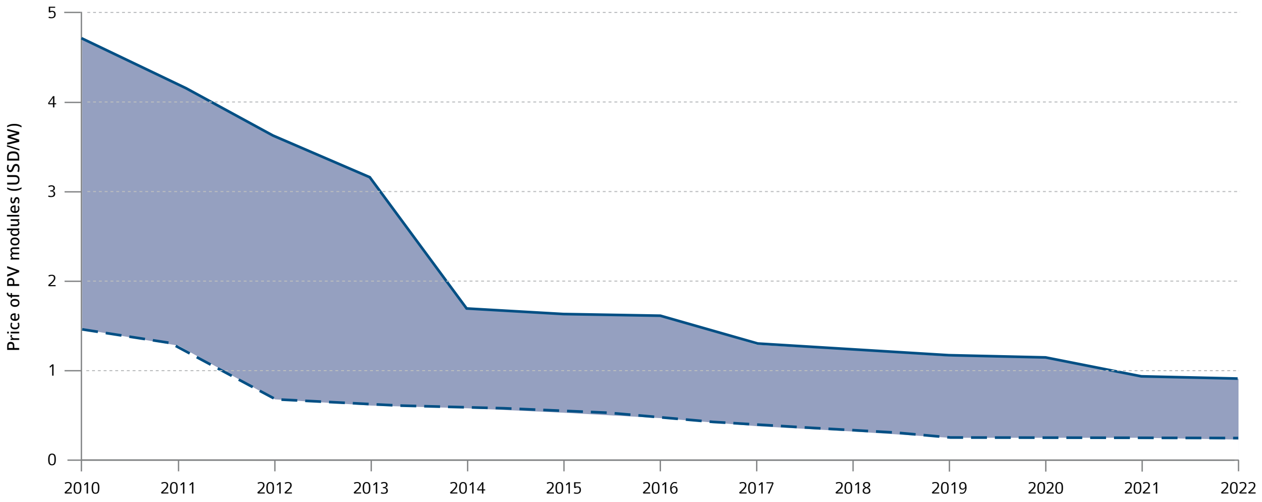
## MODULE PRICES / CONTINUED

**FIGURE 6.1**: PV MDOULES SPOT PRICES LEARNING CURVE (1992-2022)



SOURCE IEA PVPS & BECQUEREL INSTITUTE

**FIGURE 6.2**: EVOLUTION OF PV MODULES PRICES RANGE IN USD/W REPORTED IN IEA PVPS NATIONAL SURVEY REPORTS



SOURCE IEA PVPS & OTHERS

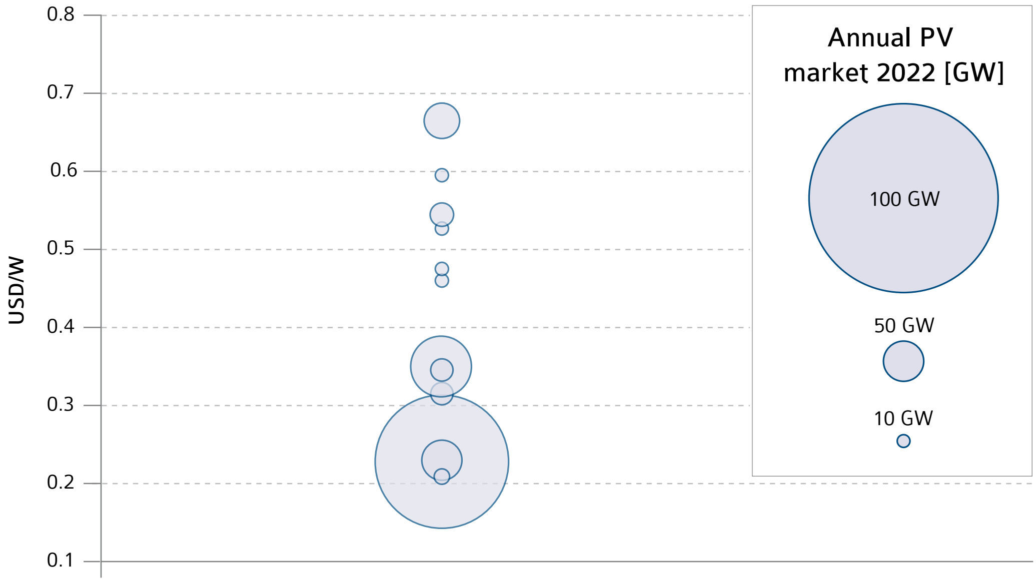
On average, the price of PV modules in 2022 (shown in Figure 6.3) accounted for approximately 40% and 50% of the lowest achievable prices that have been reported for utility scale systems. In 2022, the lowest price of modules in the reporting countries was around 0.23 USD/W, a decrease after the exceptional increase observed last year, due to disruption in the global supply chain. It is assumed that such prices are valid for high volumes and late delivery (not for installations in 2022). However, module prices for some utility-scale plants have been reported below the average values, down to around 0.20 USD/W at the end of 2022.

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 and aluminium maintained their high prices reached at the end of 2020. In addition, the whole PV value chain suffered from the important increase in transport costs. In 2022, polysilicon, wafer, cell prices stayed at high levels or continued to increase throughout most of the year with the exception of the significant dip in the last few weeks of the year caused by different factors including the production expansions and the global and Chinese New Year. Modules saw their prices decrease more gradually throughout the year, going back to mid-2021 levels. In 2022, transport costs decreased significantly to early 2020 values.

With prices below 0.20 USD/W seen on the market, generating benefits is challenging and it is generally admitted that most companies are not selling a large part of their production at these low levels. It is also clear that such prices can be considered below the average production costs of many companies, even if production costs are declining as well. 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. The decrease in polysilicon and wafer costs also led to some PV modules' price decreases without cost improvements at cell and module levels.

Higher module prices are still observed, depending on the market. For instance, the prices in Japan are consistently higher than in Germany and the USA, while average selling prices were in general still in the 0.3 USD/W to 0.4 USD/W range for most producers.

**FIGURE 6.3**: INDICATIVE MODULE PRICES IN REPORTING COUNTRIES



SOURCE IEA PVPS & OTHERS

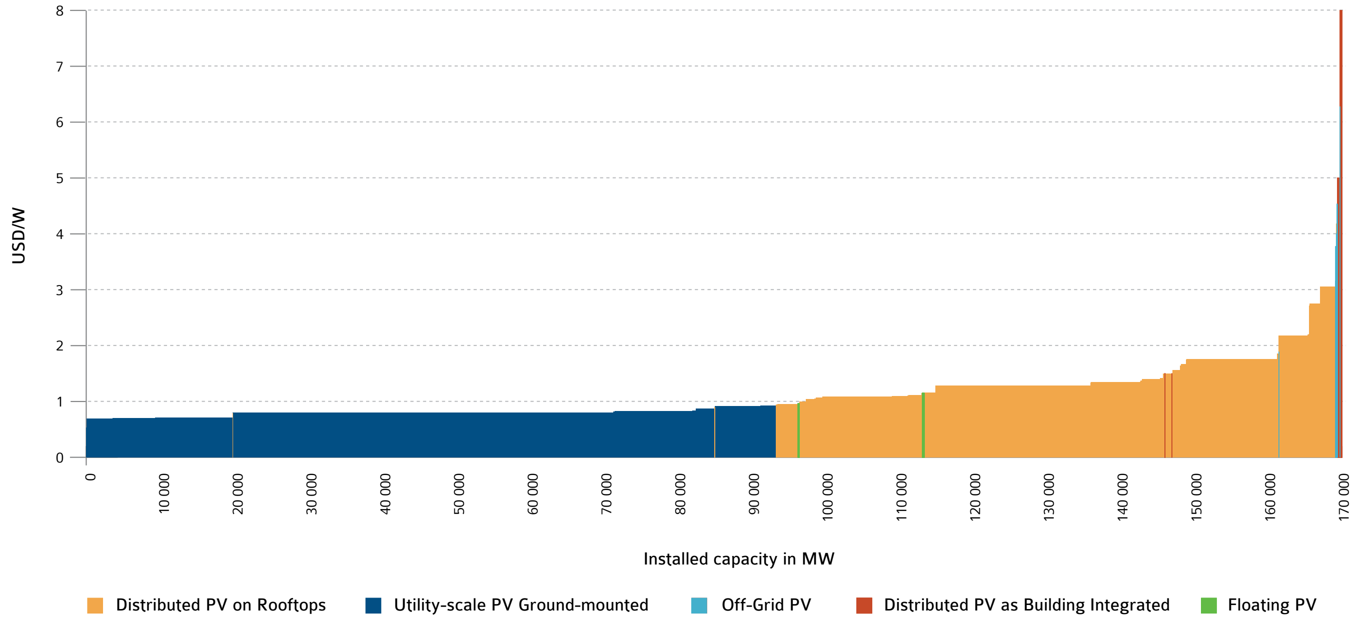
# SYSTEM PRICES

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. The highest prices haven't been included in the figures given very low level of installations and off-grid prices have been averaged in the figures for readability reasons. 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 2022. It shows that around 55 % of the PV market consists of prices below 1 USD/W. Large distributed PV systems start around 0.94 USD/W while utility-scale PV saw prices as low as 0.53 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.

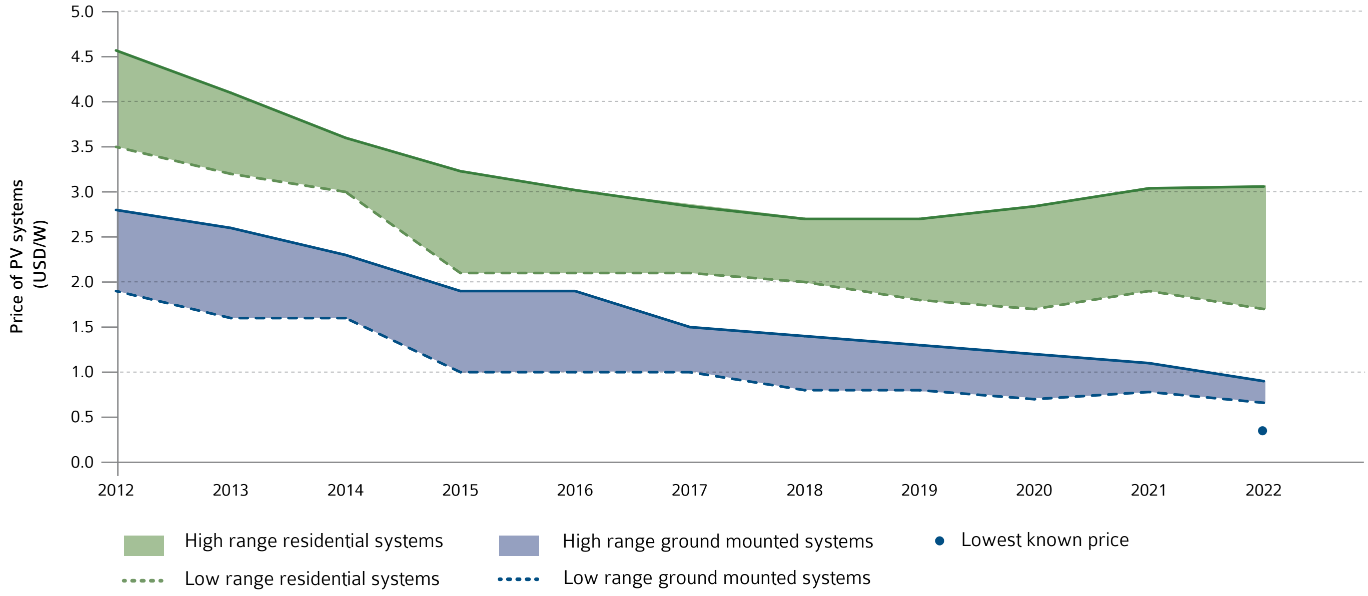
In general, the price range decreased from the previous year for all applications. On average, system prices for the lowest-priced off-grid applications are significantly higher than for the lowest-priced grid-connected applications. This is mainly attributable to the relatively higher transport costs 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 2022, the lowest system prices in the off-grid sector, irrespective of the type of application, typically ranged from about 2 USD/W to 6 USD/W but prices for some specific applications can be higher. In 2021 and 2022, an increased number of floating PV projects have been realized, in particular in Asia (China, India, Bangladesh) and Europe, but with project examples in the Americas as well as in the Middle East and Africa.

**FIGURE 6.4**: 2022 PV MARKET COSTS RANGES



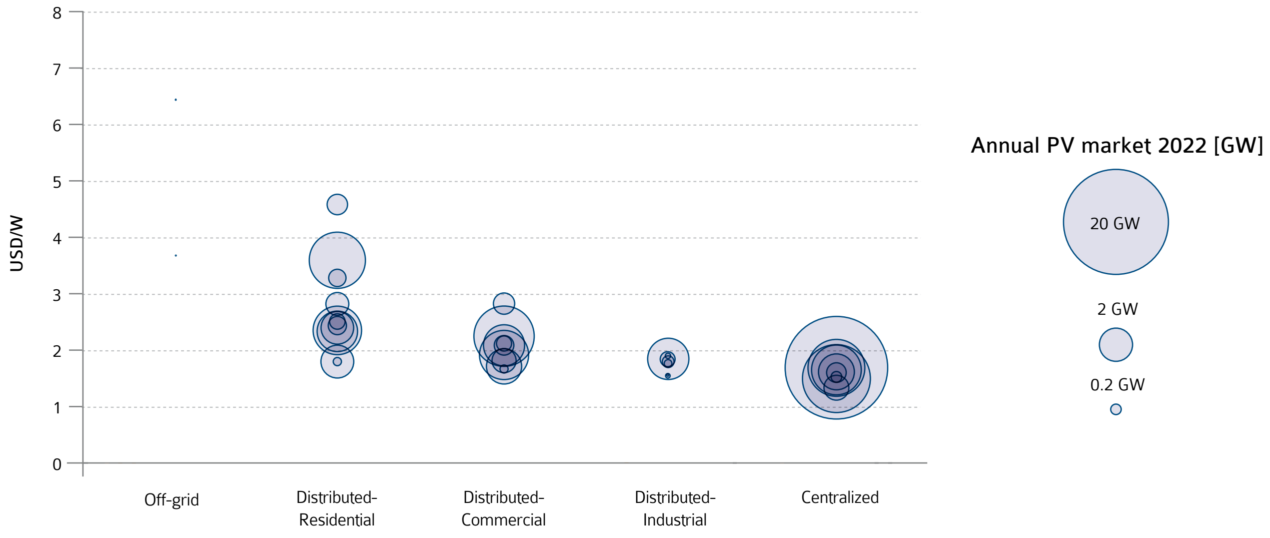
The large range of reported prices in Figure 6.5 is a function of the country and project-specific factors, These costs are reported here in US dollars using annual exchange rates - and the annual exchange rates impact apparent price curves. For example, the USD to yen (Japan) exchange rate has ranged from under 70 yen to the dollar in 2011 to nearly 150 yen to the dollar in 2022. Consequently, a fuller understanding of system price range can be reached by looking at individual country price curves (in NSR reports) as well as the aggregated data here.

**FIGURE 6.5**: EVOLUTION OF RESIDENTIAL AND GROUND-MOUNTED SYSTEMS PRICE RANGE 2012 - 2022 (USD/W)



SOURCE IEA PVPS & OTHERS

**FIGURE 6.6**: INDICATIVE INSTALLED SYSTEM PRICES IN SELECTED IEA PVPS REPORTING COUNTRIES IN 2022



SOURCE IEA PVPS & OTHERS

## SYSTEM PRICES / CONTINUED

Figure 6.6 does demonstrate a trends to a widening range of prices for residential systems as the types of applications increases - prices typically ranged from 2 USD/W to 3.5 USD/W in 2022 while prices for utility-scale PV systems seem to converge as market competitiveness becomes increasingly important, and prices typically ranged from 0.66 USD/W to 0.96 USD/W in 2022 according to the data collected. 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 simple 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. It should also be noted that these values are based on values for the surveyed countries and do not cover what are potentially the countries with the most competitive systems – for example, in the MENA region and India, where low labour costs for very large scale systems lead to regular low system costs.

The lowest achievable installed price of grid-connected systems in 2022 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 decreased by the end of 2022, following the trends of module prices and the balance of the system while soft costs and margins remained stable. System prices below 0.6 USD/W for large-scale PV systems were common in very competitive tenders, and the lowest known price was 0.4 USD/W. 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 lower LCOE. The use of bifacial modules only leads to a marginally higher CAPEX while enabling significantly lower LCOE.

## 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. 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. 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 consumed 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 will allow for increases in 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.).

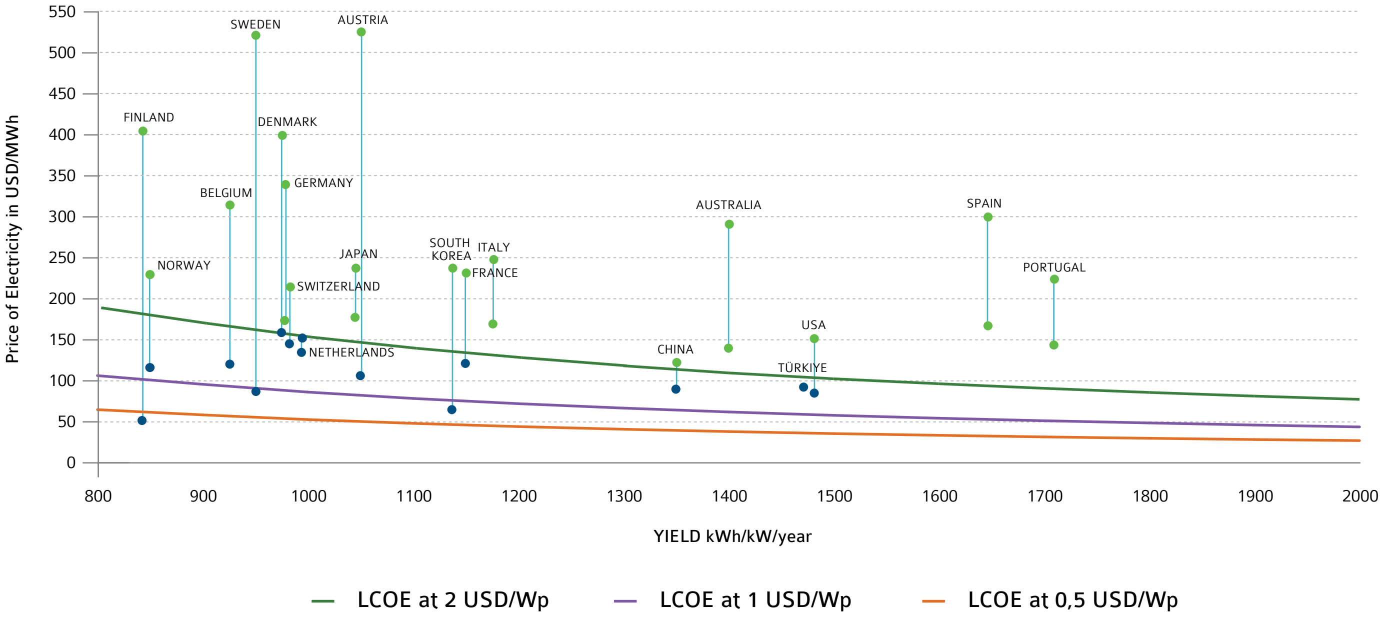
If only a part of the electricity produced can be self-consumed, then the remainder must be injected into the grid and should generate revenues of the same order as any centralised production of electricity. Today this is often guaranteed for small size installations by the possibility of receiving a FiT (or similar) for the injected electricity. Nevertheless, if we consider how PV could become competitive, this will imply defining a way to price this electricity so that smaller producers will receive fair revenues.

The second assumption implies that the full retail price of electricity could be compensated. The price paid by electricity 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 a measure; 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 may be considered given the loss of revenues for grid operators or a better understanding of PV positive impacts on the grid should be achieved.

**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).

# COST OF PV ELECTRICITY / CONTINUED

Figure 6.7 shows how grid parity has already been reached in several countries and how declining electricity costs are paving the way for more countries becoming competitive for PV. In 2022, retail electricity prices remained at high levels in a number of countries thus further strengthening the competitiveness of PV. The figure 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 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 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 with low maintenance costs and a low cost of capital. Plants have been commissioned in recent years in **Spain**, **Germany** or **Chile** which rely only on remuneration from electricity markets. It is highly probable that energy-only markets will be completed by grid services and similar additional revenues. In 2021, under rising electricity prices, such business models allowed plants to take full advantage of the short-term conjuncturally favourable situation and this in spite of the PV systems price increase observed in the same year. Such plants are already viable and calculations show that most of western European countries for instance, from **Portugal** to **Finland**, would be suitable for such PV plants with 2022 electricity prices. Such business models remain however 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 in the long term: it is known that PV reduces prices during the midday peak when penetration becomes significant. It has also been shown in recent years that such influence on prices still has a marginal impact on prices during the entire year. With high penetration and the shift to electricity of transport and heating, the influence of PV electricity on the market price is not yet precisely known and could represent (or not) an issue in the medium to long term: either prices during PV production will stay down and impair the ability to remunerate the investment or low prices will attract additional demand and will stabilise the market prices. At this point, both options remain possible without possibilities to identify which one will develop. 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.

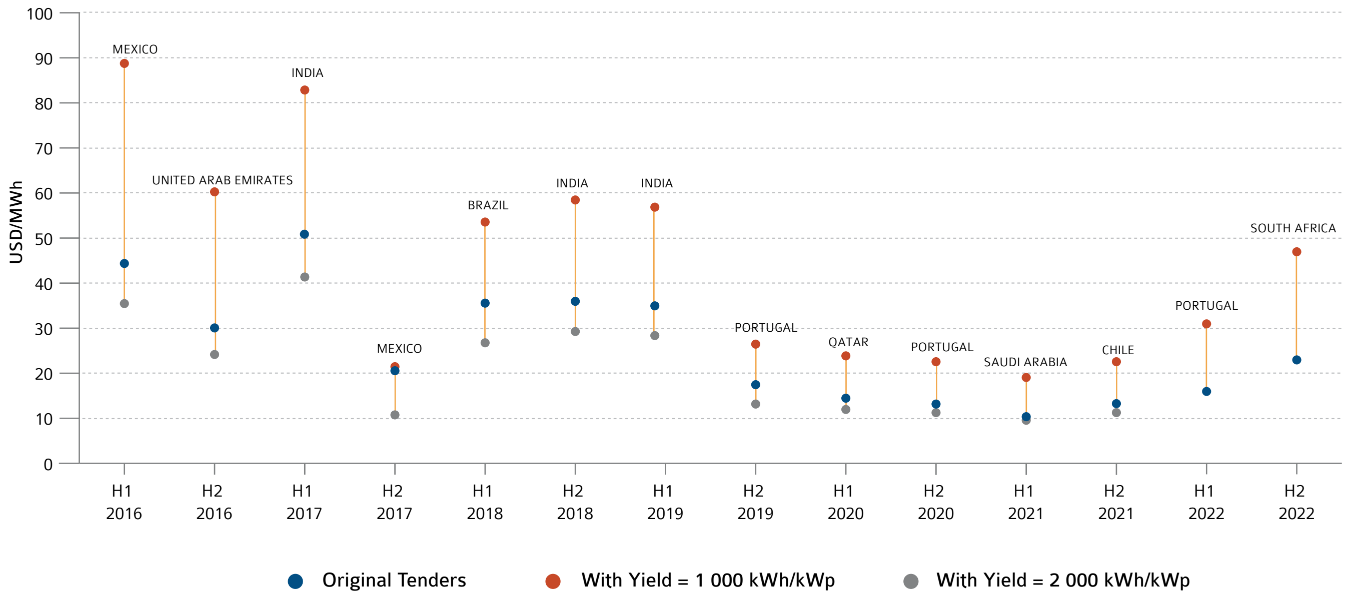
Other off-grid systems are often not replacing existing generation sources but providing electricity in places with no network and no or little use of diesel generators. They represent a completely new way to provide electricity to hundreds of millions of people all over the world.

## PRODUCING COMPETITIVE GREEN HYDROGEN WITH PV

The declining cost of PV electricity opens the door for other applications and especially the possible production of "green" hydrogen directly from PV (possibly in combination with wind). While this business model is being explored in **Australia**, **Chile**, **China**, **France**, **Japan**, **South Korea**, **Portugal**, **Spain** and the **USA**, the cost of PV electricity should reach lower levels, while the cost of electrolysers should decrease as well to make green hydrogen competitive. This perspective is not so far away, and some start to envisage a possible competitiveness in the coming years for specific uses of hydrogen. The competitiveness with "black" hydrogen seems still unreachable for the time being (even if the war in Ukraine and the sanctions against Russia have led to natural gas prices increase across the world but especially in Europe, pushing the competitiveness of green hydrogen), other uses in transport, some industrial applications and possibly agriculture (through ammonia), might create a tremendous opportunity for PV to produce hydrogen without being connected to the grid. Such a development would possibly increase the PV market significantly outside of the constraints it experiences for the time being.

## LOW TENDERS PRICES

**FIGURE 6.8.A**: NORMALISED LCOE FOR SOLAR PV BASED ON LOWEST* PPA PRICES 2016 - Q4 2022

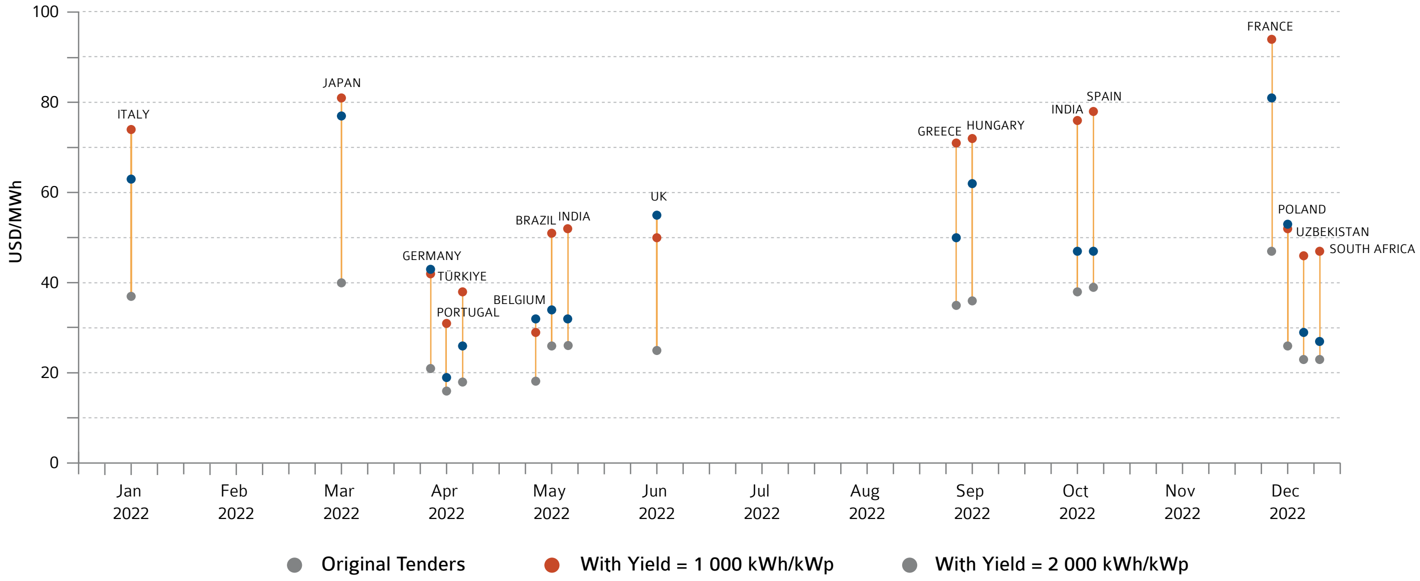


* BASED ON LOWEST PPA PRICES PER SEMESTER

SOURCE IEA PVPS & OTHERS

# COST OF PV ELECTRICITY / CONTINUED

**FIGURE 6.8.B**: NORMALISED LCOE FOR SOLAR PV BASED ON RECENT PPA PRICES 2022



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, although reported PPA values slightly increased on average compared to 2021, low prices were observed again, but no records were set. These levels are sufficiently low to be mentioned since they approach, or in many cases beat, the price of wholesale electricity in several countries. While these tenders do not represent the majority of PV projects, they have shown the ability of PV technology to provide extremely cheap electricity under the condition of a low system price (below 0.5 USD/W) and a low cost of capital.

The question of competitiveness with wholesale market prices (in countries where such market for electricity exists), depends highly on the average market prices seen. In Europe, 2022 has experienced such a meteoric market price increase (up to 1 000% increase compared to early 2021) that PV price variations have no impact at all on the competitiveness of PV: while the LCOE of PV can be estimated for utility-scale plants in Europe between 20 and 60 EUR/MWh, market prices ranging from 200 to 650 EUR/MWh have been seen in numerous countries (spot price). While these prices are highly influenced by the 2022 high gas prices resulting from the war in Ukraine and the sanctions against Russia, they nonetheless constitute a record level that makes PV competitive in all cases.

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

| REGION | COUNTRY/STATE | USD/MWH | YEAR |
|---|---|---|---|
| MIDDLE EAST | SAUDI ARABIA | 10.40 | 2021 |
| EUROPE | PORTUGAL | 13.20 | 2020 |
| LATIN AMERICA | CHILE | 13.32 | 2021 |
| MIDDLE EAST | UNITED ARAB EMIRATES | 13.53 | 2020 |
| MIDDLE EAST | QATAR | 14.49 | 2020 |
| MIDDLE EAST | SAUDI ARABIA | 14.80 | 2021 |
| EUROPE | SPAIN | 14.98 | 2021 |
| EUROPE | PORTUGAL | 15.56 | 2019 |
| LATIN AMERICA | BRAZIL | 17.50 | 2019 |
| ASIA | UZBEKISTAN | 17.91 | 2021 |

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 |
| MIDDLE EAST | SAUDI ARABIA | 10.4 | 2021 |
| NORTH AMERICA | MEXICO | 20.6 | 2017 |

SOURCE IEA PVPS & OTHERS

# seven

## PV IN THE ENERGY SECTOR

## PV ELECTRICITY PRODUCTION

### TRACKING OF PV INSTALLED CAPACITY AND MONITORING OF PV PRODUCTION

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.

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 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. 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. Indeed, a system installed at the end of the year will have produced only a small fraction of its theoretical annual electricity output, and one installed west facing will generate less over the year than one installed facing the equator. For these reasons, the electricity production from PV per country in this report is an estimate that we will call "average theoretical production".

To calculate the average theoretical PV production, the average solar yield in the country is used. The number has been provided through National Survey Reports, as well as additional sources and is an approximation of the reality. As a reminder, PV production cannot be calculated based on the AC value but requires the DC value and the characteristics of the PV plant.

### DECOMMISSIONING, REPOWERING AND RECYCLING

Data published by IEA PVPS reports on new annual installed capacity and total cumulative installed capacity are based on official data in reporting countries. 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.

# PV ELECTRICITY PRODUCTION / CONTINUED

Repowering is still relatively unusual given the age of the oldest installations, but it is expected to increase in the near future - serial defects with backsheets manufactured in the period 2009 – 2011 is a good example, as the past 2 years have seen a few hundred MW replaced. 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, and 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.

In the coming years, IEA PVPS will follow the dynamic evolution of decommissioning, repowering and recycling closely, with the expected impact on the installed capacity, market projections for repowering and the decline in PV performances due to ageing PV systems.

## PV PERFORMANCE LOSSES

The calculation of the evolution of a PV system performance is crucial to provide more accurate values to be used in yield assessments not only in terms of absolute value. In order to be able to judge a system performance, the performance loss (PL) must be calculated. The calculation of PL in PV systems is not trivial as the “true” value remains unknown. Several methodologies have been proposed, however there is no consensus nor a standardized approach to the calculation. The combination of temperature corrected Performance Ratio (PR) with the use of Year on Year or STL time decomposition performs very well compared to others.

Within the IEA PVPS Task 13, a group of experts representing several leading R&D centres, universities and industry companies is developing a framework for the calculation of Performance Loss Rates (PLR) on a large number of commercial and research PV power plants and related weather data coming from various climatic zones. Various methodologies are applied for the calculation of PLR, which are benchmarked in terms of uncertainties and “true” values. The aim of the international collaboration is to show how to calculate the PLR on high quality data (high time resolution, reliable data, irradiance, yield, etc.) and on low quality data (low time resolution, only energy data available). Various algorithms and models, along with different time averaging and filtering criteria, can be applied for the PLR calculation, each of which can have an impact on the results. The approach considers three pathways to ensure broad collaboration and increase the statistical relevance of the study and the combination of metrics (PR or power based). Furthermore, methodologies are benchmarked in terms of deviation from the average value and in terms of standard deviation. Read the full report “Assessment of Performance Loss Rate of PV Power Systems” on the IEA-PVPS website.

## 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 based on cumulative PV capacity at the end of 2022, close to optimum siting, orientation, and yearly weather conditions. PV generation is easy to measure for an individual system but more complex for an entire country. Electricity self-consumed by prosumers is generally not metered. Electricity demand is obtained via publicly available databases and via the IEA PVPS experts.

Many other countries have lower production numbers, but in total 36 countries produced at least 1% of their electricity demand from PV in 2022.

Converting installed capacity to electricity is subject to errors - solar irradiation can vary depending on the local climate; weather can differ from year to year. Systems installed in December will have produced only a fraction of their annual electricity output; systems installed on buildings may not be at optimum orientation or may have partial shading during the day. 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 (e.g., in 2022 national organisations reported on real production data in **France**, gave the PV penetration at 4%, just under estimations for this report at 4.9% and in **Spain** authorities reported it below our estimated 19.7%. 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. Numbers are hence estimates and may differ from official PV production numbers in some countries -they should be considered as indicative, providing a reliable estimation for comparison between countries and do not replace official data.

## **TABLE 7.1**: 2022 PV ELECTRICITY STATISTICS IN IEA PVPS COUNTRIES

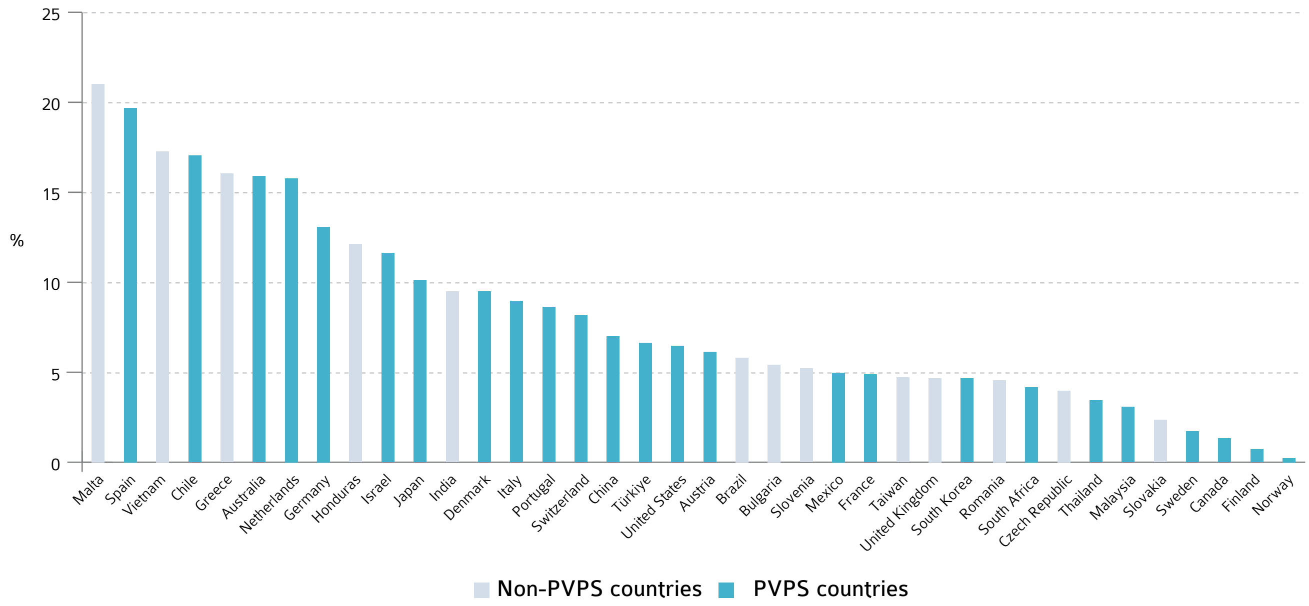
| COUNTRY | FINAL ELECTRICITY CONSUMPTION 2022 | HABITANTS 2022 | GDP 2022 | SURFACE | AVERAGE YIELD | PV ANNUAL INSTALLED CAPACITY 2022 | PV CUMULATIVE INSTALLED CAPACITY 2022 | PV ELECTRICITY PRODUCTION | ANNUAL CAPACITY PER CAPITA | CUMULATIVE CAPACITY PER CAPITA | CUMULATIVE CAPACITY PER KM² | THEORETICAL PV PENETRATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TWh | MILLION | BUSD | KM² | kWh/ kWp | MW | MW | TWh | W/Cap | W/Cap | KW/KM² | % |
| AUSTRALIA | 267 | 26 | 1 675 | 7 690 000 | 1 400 | 4 239 | 30 368 | 43 | 165 | 1 169 | 4 | 15.9% |
| AUSTRIA | 62 | 9 | 471 | 83 883 | 1 050 | 1 009 | 3 792 | 4 | 112 | 421 | 45 | 6.5% |
| CANADA | 562 | 38 | 2 140 | 9 985 000 | 1 150 | 765 | 6 517 | 7 | 20 | 172 | 1 | 1.3% |
| CHILE | 79 | 19 | 301 | 756 096 | 1 699 | 1 759 | 7 924 | 13 | 92 | 412 | 10 | 17.0% |
| CHINA | 7 714 | 1 400 | 17 963 | 9 634 000 | 1 300 | 105 545 | 414 065 | 538 | 75 | 296 | 43 | 7.0% |
| DENMARK | 35 | 6 | 395 | 44 000 | 975 | 1 573 | 3 423 | 3 | 265 | 577 | 78 | 9.5% |
| FINLAND | 82 | 6 | 281 | 338 432 | 850 | 274 | 691 | 1 | 49 | 124 | 2 | 0.7% |
| FRANCE | 459 | 68 | 2 783 | 551 500 | 1 160 | 2 966 | 19 703 | 23 | 44 | 290 | 36 | 5.0% |
| GERMANY | 503 | 83 | 4 072 | 357 170 | 978 | 7 193 | 67 301 | 66 | 87 | 800 | 188 | 13.1% |
| ISRAEL | 68 | 9 | 522 | 20 770 | 1 750 | 1 158 | 4 507 | 8 | 125 | 485 | 217 | 11.6% |
| ITALY | 318 | 59 | 2 010 | 301 336 | 1 137 | 2 470 | 25 064 | 28 | 42 | 425 | 83 | 9.0% |
| JAPAN | 883 | 125 | 4 231 | 377 975 | 1 050 | 6 653 | 85 066 | 89 | 53 | 680 | 225 | 10.1% |
| SOUTH KOREA | 594 | 52 | 1 665 | 100 401 | 1 137 | 3 114 | 24 313 | 28 | 60 | 469 | 242 | 4.7% |
| MALAYSIA | 154 | 33 | 406 | 330 621 | 1 314 | 1 068 | 3 611 | 5 | 33 | 111 | 11 | 3.1% |
| MEXICO | 291 | 130 | 1 414 | 1 964 380 | 1 708 | 680 | 8 879 | 15 | 5 | 68 | 5 | 5.2% |
| NETHERLANDS | 115 | 18 | 991 | 41 500 | 994 | 3 900 | 18 249 | 18 | 222 | 1 031 | 440 | 15.8% |
| NORWAY | 133 | 5 | 579 | 323 806 | 850 | 153 | 354 | 0 | 28 | 64 | 1 | 0.2% |
| PORTUGAL | 47 | 10 | 252 | 92 225 | 1 613 | 890 | 2 537 | 4 | 86 | 245 | 28 | 8.6% |
| SPAIN | 251 | 47 | 1 398 | 505 990 | 1 646 | 8 460 | 29 974 | 49 | 178 | 632 | 59 | 19.7% |
| SWEDEN | 137 | 11 | 586 | 410 000 | 950 | 850 | 2 457 | 2 | 81 | 233 | 6 | 1.7% |
| SWITZERLAND | 57 | 9 | 808 | 41 285 | 980 | 1 084 | 4 740 | 5 | 123 | 538 | 115 | 8.1% |
| SOUTH AFRICA | 197 | 60 | 351 | 1 219 090 | 1 733 | 112 | 4 742 | 8 | 2 | 79 | 4 | 4.2% |
| THAILAND | 190 | 70 | 495 | 1 219 092 | 1 522 | 200 | 4 278 | 7 | 3 | 61 | 4 | 3.4% |
| TÜRKIYE | 284 | 85 | 906 | 783 560 | 1 500 | 1 610 | 12 526 | 19 | 19 | 147 | 16 | 6.6% |
| USA | 4 302 | 333 | 25 463 | 9 147 282 | 1 985 | 21 127 | 141 556 | 281 | 63 | 425 | 15 | 6.5% |
| IEA PVPS | 17 784 | 2 711 | 72 160 | 46 319 394 | 1 300 | 178 852 | 926 637 | 1 265 | 66 | 342 | 20 | 7.1% |
| BRAZIL | 579 | 214 | 1 920 | 30 530 | 1 506 | 9 851 | 23 559 | 35 | 46 | 110 | 772 | 6.1% |
| INDIA | 1 355 | 1 393 | 3 385 | 357 172 | 1 625 | 18 135 | 79 147 | 129 | 13 | 57 | 222 | 9.5% |
| NON IEA PVPS | 7 216 | 5 126 | 28 843 | 88 006 041 | 1 300 | 56 976 | 256 808 | 274 | 11 | 50 | 3 | 3.8% |
| WORLD | 25 000 | 7 837 | 101 003 | 134 325 435 | 1 300 | 235 828 | 1 183 445 | 1 538 | 30 | 151 | 9 | 6.2% |

**SOURCE** IEA PVPS & OTHERS

## PV ELECTRICITY PRODUCTION / CONTINUED

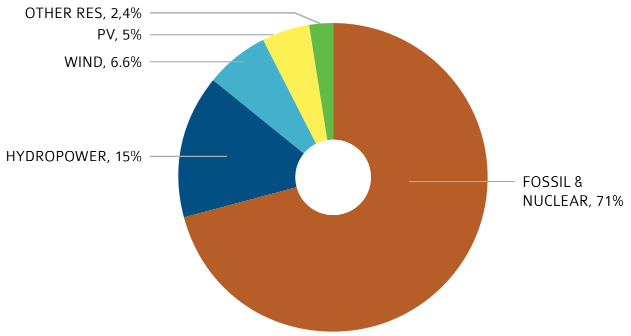
Concerning global PV penetration, with around 1 183 GW installed worldwide, PV could produce almost 1 538 TWh (see Table 7.1) of electricity on a yearly basis. This represents around 6.2% of the global electricity demand covered by PV, up 1% on 2021 – with a wide range of differing contributions from one country to another, as demonstrated in Figure 7.1.

**FIGURE 7.1**: PV CONTRIBUTION TO ELECTRICITY DEMAND 2022



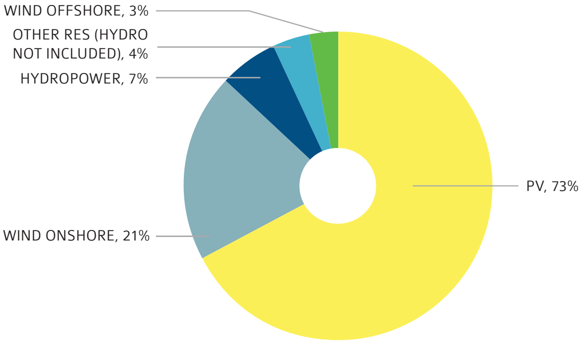
SOURCE IEA PVPS & OTHERS

**FIGURE 7.2**: SHARE OF RENEWABLE IN THE GLOBAL ELECTRICITY PRODUCTION IN 2022



SOURCE REN21, IEA PVPS

**FIGURE 7.3**: NEW RENEWABLE INSTALLED CAPACITY IN 2022



SOURCE REN21, IEA PVPS

# PV INTEGRATION AND SECTOR COUPLING

## NETWORKS, THE NECESSARY BACKBONE FOR INTEGRATING PV INTO ENERGY SYSTEMS

As PV becomes one of the most competitive tools for the energy transition, across the world more and more governments, energy agencies and transmission system operators are integrating significant volumes of PV into their transition scenarios. These scenarios, whether built on market forecasts, climate and policy goals or blue-sky thinking all imply adequate network infrastructure to integrate new PV. This network infrastructure ranges from wires and transformers to distribution substations, transmission substations, transmission networks and inter-regional connections for centralised generation and high projected penetration rates.

The IEA PVPS Task 14 goal is to promote the use of network-connected PV as an important source in electric power systems at high penetration levels and to reduce the technical barriers to achieving high penetration levels of distributed renewable systems. Task 14 has published a number of reports providing insight into tools and requirements on this subject.

There are several interlinked aspects to network integration that impact the deployment of PV, and these include:

- Network management governance
- Network infrastructure (wires, substations etc) and planning
- Network connection procedures, delays, and financial contributions
- Annual network access requirements, and costs
- Curtailment, balancing and reactive power regulation

Governance determines much from cost sharing to network connection procedures and delays. Some countries have highly decentralised ownership and governance of transmission and/or distribution networks (**USA**, **Germany**) whilst others have near monopolies (sometimes through layers of subsidiary companies) or state-run networks (**Denmark**, **France**, the **Netherlands**, **Brazil**). Whilst governance models vary across the world, the PV sector has been general in its call for transparency and the ability to participate in the decision-making process, The governance models can further by complicated by mission statements that do not include generators as primary customers; where a grid operator's mission is to "service consumers", it can be difficult for generators to advocate successfully for a voice in consultative boards and the decision-making process. As decentralised generation grows and consumers increasingly become prosumers, there is hope that, where needed, reforms will facilitate long term planning and equitable participation.

Regional interconnections are a key element to growing capacity worldwide - interconnections with neighbouring countries combined with international electricity trade contribute to lower electricity prices, improve security of supply and reduce the need to build new power plants and flexibility assets to manage renewable power sources like solar and wind. The EU has an indicative target of 15% interconnection towards 2030 and 93 GW additional cross-border capacity by 2040 to facilitate the EU Green Deal, whilst the ASEAN (Association of Southeast Asian Nations) project for an interconnected network would connect Asia to Oceania with strong support from **Singapore** (landmarks include transmission of RES from Vietnam in 2022, the 2023 Memorandum of Understanding with Indonesia and continued support for the Australia–ASEAN Power Link).

On a national level, **Australia** has created Renewable Energy Zones to coordinate investments in transmission capacity to bring generation from concentrated zones of large-scale RES deployments to urban areas.

Distribution network capacity is also a dimensioning factor, and whilst planning remains key, the multiplicity of actors and governance frameworks means that as many frameworks as countries exist. For those countries with monopolistic distribution network operators, investment can be coordinated (**France** contracted an 800 million EUR loan in 2022 to finance upgrades) whereas in other countries local utilities are left to manage investments as they can, or rely on government oversee to develop coordinated plans (**Austria**, **Sweden**, for example).

Despite the overall benefits of network expansion, the costs of network upgrades must still be distributed between the end users through network tariffs, also called grid tariffs. Network tariffs are designed to recover the costs of investing and operating electricity networks; these can be separated into two distinct categories; tariffs for connecting to the network; and annual access fees.

Network connection policies cover both fees but also procedures and technical regulations (network codes). Network connection policies can vary greatly – in many countries, the cost of initial connection must cover part or all of the costs for new infrastructure for the generator (wires, sub-stations, transmission capacity upgrades), whilst in others these costs are managed through annual access fees. Transparency is an issue in many regions as generators struggle to access information on connection capacity and costs before developing projects, often leading to stranded development costs or difficulty obtaining early financing.

# PV INTEGRATION AND SECTOR COUPLING / CONTINUED

Lack of transparency can also cause contestation with cost sharing as upgrades may be financed sequentially by different generators, with the first generators financing capacity upgrades for later arrivals - or, alternatively, using remaining capacity leaving later arrivals to finance upgrades alone. But it is not all about cost: for example, in **Spain** an innovative approach to allocation procedures includes measures to promote local benefits and local investment. Network connection delays are being experienced in many countries (**USA**, **Japan**, **India**, **Brazil**, **Spain**, **Austria**, **France**, **Sweden**) as demand increases, with delays being attributed to construction times, material availability (transformers), lack of manpower and the length of permitting and administrative procedures. Where network capacity is not adequate to meet demand, different policies have been used, most commonly delaying connection until capacity is available or offering connection with curtailment policies.

Network codes include requirements that must be met at connection to ensure that continued access respects network policies. Network codes have been reviewed in the European Union in an attempt to harmonise network codes between member states and will lead to additional constraints for PV systems. In **Australia**, specific network codes have been adapted for PV and more will come. In **Mexico**, specific network requirements have in some cases been imposed to bidders in tendering processes. Network integration policies will become an important subject in the coming years, with the need to regulate PV installations in densely equipped areas.

Once connected to the network, network access requirements and fees covers how systems must operate and their contribution to network use and investment. Depending on local policies, network access fees can range from zero to high enough to impact project feasibility. They can be used to guide projects to specific zones or power segments, support self-consumption projects or on the contrary discourage them. These fees are generally built on a combination of capacity-based costs and energy consumption/ injection costs and may also include reactive power costs or compensations (for curtailment or network downtime, and in more advanced markets, for additional services (ancillary services)).

Whilst reinforcing infrastructure is the most straightforward method of increasing network capacity, it may be neither the most cost-efficient and is rarely the fastest: in some cases, local storage or demand side management might be available at a lower cost, whilst time-variable and location-based fees can also reduce investments without reducing the volume of PV that can be integrated to a network.

Cost-reflective rate structures could and should provide the right incentives to develop local storage or load control. Tariffs are effective tools to drive investments, however, some objectives could require conflicting price signals and it will be important to adapt fee structures as network integration goals change with time. In particular, several countries are discussing or implementing the total or partial shift of network costs from an energy-based structure towards a capacity-based structure (Flanders region in **Belgium**): this could impact the profitability of distributed and self-consumption PV plants if all network costs become due, even with large shares of the energy produced on site. Some network operators see their revenue and therefore their capacity to invest and maintain the network, being reduced significantly in the future if prosumers or semi-independent energy communities become the new normal as they will lose energy consumption-based fees. However, recent studies tend to indicate that the increasing electrification of usages is likely to compensate losses without requiring significant changes to price structures. Despite the role that network tariffs can play to give price signals to consumers, other tools exist and can be required to achieve certain goals- the priority of network tariffs should be to accurately reflect cost while also keeping the overall rationale transparent, future-proof and simple for consumers to understand and implement.

Technical solutions to increase capacity without additional infrastructure investments include curtailment and pro-active reactive power management. In the EU, and countries with increasing network penetration such as **USA**, **Australia**, **Japan**, network codes are slowly activating these levers to enable a faster energy transition. Curtailment involves reducing the capacity of a system to inject energy to the network at a given moment or above a certain power level; it can be dynamic, with sophisticated smart controls determining when and how much should be curtailed, or much simpler, imposing a limitation on injections at fixed times or during a period as infrastructure is built. Whilst curtailment is seen both as a solution and a risk for widespread deployment of PV, it is likely to continue to be actively used in an increasing number of countries.

**See the IEA PVPS Task 16 report on Firm Power Generation for the role curtailment could play in 100% variable renewable energy networks.**

As the cost of climate change increases, so is the acceptability of investment in the energy transition. Network upgrades and infrastructure investments are proving to be an essential part of planning the energy transition, with significant budgets being dedicated. Network operators are increasingly adopting solutions that increase network capacity without waiting for infrastructure reinforcements to come online – at least in some countries. To ensure a least cost energy transition for the public work towards including consumers, generators and the civil society in network governance is an essential step.

## THE ENERGY STORAGE MARKET

Energy storage can take different forms – when coupled with PV, the most common are batteries in standalone systems, generally found in residential systems far from the grid, distributed residential batteries increasingly used to improve self-consumption rates, batteries keeping micro grids stable providing both services and energy, and big batteries that are slowly being deployed to provide system services.

In general, distributed battery storage is seen as an opportunity to solve grid integration issues linked to PV and to increase the self-consumption ratio of distributed PV plants. Despite their decreasing costs, such solutions are not yet economically viable in all countries and market segments – with some stand out countries such as certain states in the **USA**, and **Australia**. However, the adoption of batteries is on the rise both in residential segments and in commercial segments as more and more consumers are willing to maximise their self-consumption and to optimize their consumption profile. In some countries, this is encouraged to relieve grid congestion or peak loads, either through subsidies (**Australia**, **Austria**, **Spain**, the **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**).

More large-scale PV plants are being built in combination with batteries, which can be used to stabilize grid injection, reduce curtailment, and, in some cases, to 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, however this trend would require some more years to be confirmed. On their own, dozens of big batteries (utility scale) have been installed around the world, and many more are in project – and system size is increasing each year, as can be seen by looking to those installed in 2021 and 2022 in **Australia**, **China**, and the **USA**. It is increasingly evident that battery storage is a multipurpose tool to reduce the need for turbine-based generation in electricity networks.

Globally, the largest part of batteries sold are used for transportation in EVs and stationary storage remains the exception with smaller volumes. However, the rapid development of electric mobility is driving battery prices down much faster than any could have expected in the stationary market alone. This could give a huge push to the development of storage as a tool to ease PV installations in some specific conditions.

## THE ELECTRIFICATION OF TRANSPORT

The electrification of transport is accelerating in many countries and whilst the link between PV development and EVs is not yet fully understood, the growth of self-consumption policies and grid congestion limiting injections are factors to be considered. Charging EVs during peak load implies rethinking power generation, grid management and smart metering, and concepts such as virtual self-consumption could rapidly provide a framework for EVs as mobile storage for excess PV generation.

### 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 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

## 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 more prevalent.

Several European manufacturers of electric domestic hot water tanks are now offering specific electronic devices to directly link extra PV production to an electric boiler. Hot water tanks enable users to improve self-consumption rates or reduce grid injection of excess generation to zero, especially as grid access costs come to include fees for injections. More single household owners with PV systems are taking an interest in those in order to increase self-consumption. Specific recommendations exist for connection and metering of storage systems in **Switzerland** for instance.

In hot climates such as **Australia**, **China** as well as the states of Florida and California (**USA**), PV has already been used to provide electricity for cooling for several years. However, as climate change intensifies and electricity costs go up whilst grid infrastructure becomes more fragile to heatwaves, the use of PV at the point of consumption to reduce grid loads whilst cooling needs are high is becoming more and more necessary. In colder climates, the use of thermal storage in domestic hot water tanks, either directly or combined with heat pumps is also becoming more common. Beyond Europe, many countries are interested in the link between addressing the very rapidly increasing energy need for air conditioning due to the very attractive present and future cost of PV electricity. The electrification of heating and cooling through the increasing use of heat pumps will also increase demand for PV at the point of consumption.

For larger coupling, no real commercial products are available. Nevertheless, more and more designs of solar PV systems based on self-consumption are linked to some specific use of adapted water chillers including cold water storage. This axis of innovation to convert green electricity in cooling and cold storage is therefore seen by the IEA PVPS Tasks as a very promising way to absorb the peak production of PV, especially in sunny emerging economies. Indeed, in places where grid stress is very present in summertime, benefiting from solar cooling and cooling thermal storage based on local PV production can become a very powerful tool.

The use of solar energy (PV or thermal) for cooling is the subject of the IEA SHC Task 65 (https://task65.iea-shc.org/) which focuses 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 derivatives such as ammonia) is increasingly seen as a partial answer to decarbonize some sectors such as the maritime sector and long distance, heavy weight road transport. More and more research programs and early industrialization projects around the creation of green hydrogen (or other molecules) have been initiated in the past few years. 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, even if technological challenges remain.

# ANNEXES

## ANNEX 1: CUMULATIVE INSTALLED PV CAPACITY (MWp) FROM 1992 TO 2022

| COUNTRY | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUSTRALIA | 7 | 9 | 11 | 13 | 16 | 19 | 23 | 25 | 29 | 34 | 39 | 46 | 52 | 61 | 70 | 82 | 105 | 187 | 571 | 1 376 | 2 416 | 3 226 | 4 092 | 5 109 | 5 985 | 7 132 | 11 586 | 16 399 | 21 091 | 26 129 | 30 368 |
| 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 | 1 096 | 1 269 | 1 455 | 1 702 | 2 043 | 2 783 | 3 792 |
| BELGIUM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 24 | 112 | 671 | 1 108 | 2 176 | 2 870 | 3 139 | 3 245 | 3 355 | 3 535 | 3 865 | 4 310 | 5 127 | 6 273 | 7 123 | 8 149 |
| CANADA | 1 | 1 | 2 | 2 | 3 | 3 | 4 | 6 | 7 | 9 | 10 | 12 | 14 | 17 | 20 | 26 | 33 | 95 | 281 | 559 | 766 | 1 211 | 1 843 | 2 519 | 2 665 | 2 913 | 3 130 | 3 388 | 3 713 | 5 752 | 6 517 |
| CHILE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 12 | 221 | 576 | 1 125 | 1 837 | 2 406 | 2 694 | 3 484 | 6 165 | 7 924 |
| CHINA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 16 | 34 | 44 | 54 | 62 | 72 | 92 | 132 | 292 | 792 | 3 492 | 6 692 | 17 682 | 28 322 | 43 472 | 78 022 | 130 882 | 175 142 | 205 440 | 253 640 | 308 520 | 414 065 |
| 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 | 1 061 | 1 139 | 1 254 | 1 362 | 1 626 | 1 850 | 3 423 |
| 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 | 691 |
| FRANCE | 2 | 2 | 2 | 3 | 4 | 6 | 8 | 9 | 11 | 14 | 17 | 21 | 24 | 26 | 38 | 76 | 218 | 440 | 1 446 | 3 562 | 4 906 | 5 692 | 6 837 | 7 920 | 8 636 | 9 713 | 10 755 | 11 930 | 13 098 | 16 737 | 19 703 |
| GERMANY | 6 | 9 | 12 | 18 | 28 | 42 | 54 | 70 | 114 | 176 | 296 | 435 | 1 105 | 2 056 | 2 899 | 4 170 | 6 120 | 10 566 | 18 006 | 25 916 | 34 077 | 36 710 | 37 900 | 39 224 | 40 679 | 42 293 | 45 181 | 490 16 | 53 901 | 60 108 | 67 301 |
| ISRAEL | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 22 | 67 | 186 | 272 | 377 | 588 | 771 | 877 | 952 | 1 358 | 1 960 | 2 414 | 3 349 | 4 507 |
| ITALY | 8 | 12 | 14 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 22 | 26 | 31 | 37 | 50 | 100 | 496 | 1 277 | 3 605 | 13 141 | 16 796 | 18 198 | 18 607 | 18 915 | 19 297 | 19 682 | 20 108 | 20 865 | 21 650 | 22 594 | 25 064 |
| JAPAN | 19 | 24 | 31 | 43 | 60 | 91 | 133 | 209 | 330 | 453 | 637 | 860 | 1 132 | 1 422 | 1 708 | 1 919 | 2 144 | 2 627 | 3 618 | 4 914 | 6 632 | 13 599 | 23 339 | 34 151 | 42 040 | 49 500 | 56 162 | 63 192 | 71 868 | 78 413 | 85 066 |
| KOREA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 9 | 14 | 36 | 81 | 357 | 524 | 650 | 729 | 1 024 | 1 555 | 2 481 | 3 615 | 4 502 | 5 835 | 8 099 | 12 665 | 17 323 | 21 199 | 24 313 |
| MALAYSIA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 4 | 34 | 145 | 213 | 273 | 352 | 401 | 918 | 1 417 | 1 961 | 2 330 | 3 611 |
| MEXICO | 0 | 0 | 9 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 25 | 31 | 40 | 52 | 112 | 179 | 246 | 311 | 485 | 3 075 | 5 001 | 6 574 | 8 199 | 8 879 |
| 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 | 829 |
| NETHERLANDS | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 5 | 9 | 16 | 22 | 40 | 43 | 45 | 49 | 59 | 69 | 111 | 170 | 390 | 767 | 1 069 | 1 536 | 2 061 | 2 914 | 4 609 | 7 225 | 10 717 | 14 349 | 18 249 |
| NORWAY | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 8 | 9 | 9 | 10 | 12 | 14 | 26 | 44 | 68 | 120 | 160 | 201 | 354 |
| PORTUGAL | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 3 | 3 | 18 | 68 | 108 | 134 | 175 | 244 | 299 | 418 | 454 | 519 | 585 | 673 | 907 | 1 077 | 1 647 | 2 537 |
| SOUTH AFRICA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 311 | 1 392 | 1 486 | 2 280 | 2 349 | 2 409 | 2 872 | 4 172 | 4 630 | 4 742 |
| SPAIN | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 14 | 25 | 52 | 150 | 742 | 4 021 | 4 070 | 4 595 | 5 080 | 5 439 | 5 566 | 5 641 | 5 706 | 5 778 | 5 928 | 6 306 | 11 628 | 15 875 | 21 513 | 29 974 |
| 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 | 1 200 | 1 606 | 2 457 |
| SWITZERLAND | 5 | 6 | 7 | 8 | 10 | 11 | 13 | 14 | 16 | 18 | 20 | 22 | 24 | 28 | 30 | 37 | 49 | 80 | 125 | 223 | 437 | 756 | 1 061 | 1 394 | 1 664 | 1 906 | 2 173 | 2 498 | 2 973 | 3 656 | 4 740 |
| THAILAND | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 30 | 32 | 33 | 43 | 49 | 243 | 387 | 823 | 1 298 | 1 420 | 2 446 | 3 056 | 3 513 | 3 529 | 3 578 | 4 078 | 4 278 |
| TURKEY | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 32 | 64 | 358 | 1 175 | 4 206 | 7 339 | 8 551 | 9 424 | 10 917 | 12 526 |
| UNITED STATES | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 111 | 190 | 295 | 455 | 753 | 1 188 | 2 017 | 3 937 | 7 130 | 12 076 | 18 321 | 25 821 | 40 973 | 51 818 | 62 498 | 76 274 | 96 131 | 120 429 | 141 556 |
| REST OF EU COUNTRIES | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 11 | 21 | 23 | 34 | 42 | 107 | 574 | 2 460 | 3 461 | 5 569 | 7 922 | 8 283 | 8 588 | 8 946 | 9 275 | 10 090 | 11 883 | 16 370 | 22 916 | 31 821 |
| TOTAL IEA PVPS | 50 | 65 | 90 | 115 | 150 | 206 | 271 | 372 | 572 | 784 | 1 143 | 1 566 | 2 698 | 4 115 | 5 551 | 8 013 | 14 885 | 22 938 | 39 797 | 69 634 | 97 051 | 131 595 | 167 047 | 208 983 | 276 272 | 360 328 | 445 384 | 528 786 | 642 854 | 778 310 | 967 436 |
| TOTAL NON IEA PVPS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 14 | 23 | 33 | 45 | 67 | 94 | 140 | 250 | 559 | 2 260 | 4 706 | 7 947 | 12 669 | 21 241 | 30 761 | 49 579 | 69 265 | 99 154 | 131 305 | 169 094 | 216 009 |
| TOTAL | 50 | 65 | 90 | 115 | 150 | 206 | 271 | 372 | 573 | 791 | 1 157 | 1 590 | 2 731 | 4 161 | 5 618 | 8 107 | 15 025 | 23 188 | 40 356 | 71 893 | 101 757 | 139 542 | 179 717 | 230 225 | 307 032 | 409 907 | 514 649 | 627 940 | 774 159 | 947 404 | 1 183 445 |

**SOURCE** IEA PVPS, BECQUEREL INSTITUTE & OTHERS

# ANNEXES / CONTINUED

## ANNEX 2: ANNUAL INSTALLED PV CAPACITY (MW) FROM 1992 TO 2022

| COUNTRY | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUSTRALIA | 7 | 2 | 2 | 2 | 3 | 3 | 4 | 3 | 4 | 4 | 6 | 6 | 7 | 8 | 10 | 12 | 22 | 83 | 383 | 806 | 1 039 | 811 | 866 | 1 018 | 876 | 1 147 | 4 454 | 4 813 | 4 692 | 5 038 | 4 239 |
| 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 | 1 009 |
| BELGIUM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 18 | 88 | 559 | 437 | 1 068 | 694 | 269 | 106 | 110 | 180 | 330 | 445 | 817 | 1 146 | 850 | 1 026 |
| 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 | 2 038 | 765 |
| CHILE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 9 | 209 | 355 | 549 | 712 | 569 | 288 | 790 | 2 681 | 1 759 |
| CHINA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 5 | 19 | 10 | 10 | 8 | 10 | 20 | 40 | 160 | 500 | 2 700 | 3 200 | 10 990 | 10 640 | 15 150 | 34 550 | 52 860 | 44 260 | 30 300 | 48 200 | 54 880 | 105 545 |
| 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 | 115 | 109 | 264 | 718 | 1 573 |
| 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 | 274 |
| FRANCE | 2 | 0 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 4 | 3 | 2 | 12 | 38 | 143 | 222 | 1 006 | 2 116 | 1 344 | 786 | 1 145 | 1 083 | 716 | 1 077 | 1 042 | 1 175 | 1 168 | 3 639 | 2 966 |
| GERMANY | 6 | 3 | 3 | 6 | 10 | 14 | 12 | 16 | 44 | 62 | 120 | 139 | 670 | 951 | 843 | 1 271 | 1 950 | 4 446 | 7 440 | 7 910 | 8 161 | 2 633 | 1 190 | 1 324 | 1 455 | 1 614 | 2 888 | 3 835 | 4 885 | 6 207 | 7 193 |
| ISRAEL | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 21 | 45 | 119 | 86 | 105 | 211 | 183 | 106 | 75 | 406 | 602 | 454 | 935 | 1 158 |
| ITALY | 8 | 4 | 2 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 4 | 5 | 7 | 13 | 50 | 396 | 781 | 2 328 | 9 536 | 3 655 | 1 402 | 409 | 308 | 382 | 385 | 426 | 758 | 785 | 944 | 2 470 |
| JAPAN | 19 | 5 | 7 | 12 | 16 | 32 | 42 | 75 | 122 | 123 | 184 | 223 | 272 | 290 | 287 | 210 | 225 | 483 | 991 | 1 296 | 1 718 | 6 968 | 9 740 | 10 811 | 7 889 | 7 460 | 6 662 | 7 030 | 8 676 | 6 545 | 6 653 |
| KOREA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 1 | 3 | 5 | 22 | 45 | 276 | 167 | 127 | 79 | 295 | 531 | 926 | 1 134 | 887 | 1 333 | 2 265 | 4 566 | 4 658 | 3 876 | 3 114 |
| 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 | 543 | 370 | 1 068 |
| MEXICO | 0 | 0 | 9 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 6 | 9 | 12 | 60 | 67 | 67 | 65 | 174 | 2 590 | 1 926 | 1 573 | 1 625 | 680 |
| 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 | 130 |
| 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 | 1 695 | 2 616 | 3 492 | 3 632 | 3 900 |
| NORWAY | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 11 | 18 | 25 | 51 | 40 | 41 | 153 |
| PORTUGAL | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 14 | 50 | 40 | 26 | 41 | 69 | 55 | 119 | 36 | 65 | 66 | 88 | 234 | 170 | 571 | 890 |
| SOUTH AFRICA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 305 | 1 081 | 94 | 794 | 69 | 60 | 463 | 1 300 | 458 | 112 |
| SPAIN | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 8 | 11 | 27 | 98 | 592 | 3 279 | 49 | 525 | 485 | 359 | 127 | 75 | 65 | 72 | 150 | 378 | 5 322 | 4 247 | 5 639 | 8 460 |
| 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 | 480 | 407 | 850 |
| SWITZERLAND | 5 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 7 | 12 | 30 | 46 | 98 | 214 | 319 | 305 | 333 | 270 | 242 | 267 | 325 | 475 | 683 | 1 084 |
| THAILAND | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 7 | 2 | 1 | 10 | 6 | 194 | 144 | 436 | 475 | 122 | 1 027 | 610 | 456 | 16 | 49 | 500 | 200 |
| TURKEY | 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 | 3 031 | 3 133 | 1 212 | 874 | 1 492 | 1 610 |
| UNITED STATES | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 111 | 79 | 105 | 160 | 298 | 435 | 829 | 1 920 | 3 193 | 4 946 | 6 245 | 7 500 | 15 152 | 10 845 | 10 680 | 13 776 | 19 857 | 24 298 | 21 127 |
| REST OF EU COUNTRIES | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 | 2 | 11 | 7 | 65 | 468 | 1 885 | 1 001 | 2 109 | 2 352 | 362 | 305 | 359 | 329 | 815 | 1 793 | 4 487 | 6 546 | 8 905 |
| TOTAL IEA PVPS | 50 | 16 | 25 | 25 | 35 | 56 | 65 | 101 | 199 | 212 | 360 | 423 | 1 131 | 1 418 | 1 436 | 2 462 | 6 872 | 8 053 | 16 859 | 29 836 | 27 421 | 34 544 | 35 453 | 41 936 | 67 289 | 84 056 | 85 055 | 83 404 | 114 068 | 135 951 | 188 913 |
| TOTAL NON IEA PVPS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 | 6 | 9 | 10 | 12 | 21 | 27 | 46 | 110 | 309 | 1 701 | 2 444 | 3 242 | 4 723 | 8 571 | 9 508 | 18 818 | 19 686 | 29 878 | 32 153 | 37 789 | 46 915 |
| TOTAL | 50 | 16 | 25 | 25 | 35 | 56 | 65 | 101 | 200 | 219 | 366 | 432 | 1 141 | 1 430 | 1 457 | 2 489 | 6 918 | 8 163 | 17 168 | 31 537 | 29 865 | 37 786 | 40 175 | 50 507 | 76 797 | 102 875 | 104 741 | 113 282 | 146 221 | 173 739 | 235 828 |

# ANNEXES / CONTINUED

## **ANNEX 3**: AVERAGE 2022 EXCHANGE RATES

| COUNTRY | CURRENCY CODE | EXCHANGE RATE IN 2022 (1 USD =) |
|---|---|---|
| AUSTRALIA | AUD | 1.442 |
| CANADA | CAD | 1.301 |
| CHILE | CLP | 952.43 |
| CHINA | CNY | 6.73 |
| DENMARK | DKK | 7.077 |
| EUROZONE | EUR | 0.951 |
| ISRAEL | ILS | 3.361 |
| JAPAN | JPY | 131.454 |
| SOUTH KOREA | KRW | 1291.729 |
| MALAYSIA | MYR | 4.45 |
| MEXICO | MXN | 20.11 |
| MOROCCO | MAD | 10.275 |
| NORWAY | NOK | 9.619 |
| SOUTH AFRICA | ZAR | 16.377 |
| SWEDEN | SEK | 10.122 |
| SWITZERLAND | CHF | 0.955 |
| THAILAND | THB | 35.044 |
| TÜRKIYE | TRY | 16.572 |
| UNITED STATES | USD | 1 |

SOURCE IRS

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