Technology Collaboration Programme
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International Energy Agency
Photovoltaic Power Systems Programme

Task 1 Strategic PV Analysis and Outreach

PVPS

Snapshot of Global PV Markets 2024

Report IEA-PVPS T1-42: 2024

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 6000 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 TCPs 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.

The IEA PVPS participating countries are Australia, Austria, Belgium, Canada, Chile, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Mexico, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America. The European Commission, SolarPower Europe, the Smart Electric Power Alliance, the Solar Energy Industries Association, and the Copper Alliance are also members.

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What is IEA PVPS Task 1?

The objective of Task 1 of the IEA Photovoltaic Power Systems Programme is promoting and facilitating the exchange and dissemination of information on the technical, economic, environmental and social aspects of PV power systems. Task 1 activities support the broader PVPS objectives: to contribute to cost reduction of PV power applications, to increase awareness of the potential and value of PV power systems, to foster the removal of both technical and non-technical barriers and to enhance technology co-operation.

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COVER PICTURE

Plus Ultra Amsterdam 200kWp in the plane and on the cantilevered fins (the Netherlands). image credits: Saint Gobain Solutions/Photostuip/BIPV Nederland

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INTERNATIONAL ENERGY AGENCY
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

IEA PVPS
Task 1
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EXECUTIVE SUMMARY

The global PV cumulative capacity grew to **1.6 TW** in 2023, up from 1.2 TW in 2022, with from 407.3 GW to **446 GW[1] of new PV systems** commissioned – and in the order of an estimated 150 GW of modules in inventories across the world. After several years of tension on material and transport costs, module prices plummeted in a massively over-supplied market, maintaining the competitivity of PV even as electricity prices decreased after historical peaks in 2022.

Major trends include:

- With active development policies, China's PV installations soared to a record **235 GW_{DC}** (or even up to 277 GW[2]**)** or over 60% of new global capacity reaching 662 GW of cumulative capacity. Remarkably, this annual capacity represents over 15% of the total global cumulative capacity and is nearly the equivalent of the second largest cumulative capacity: Europe. This once again represented a more than doubled annual installed capacity, up from 105.5 GW in 2023 and 54.9 GW in 2021.
- **Europe demonstrated continued strong growth** installing **61 GW** (of which 55.8 GW in the EU**)**, led by a resurgence in Germany (14.3 GW), and increased volumes in Poland (6.0 GW), Italy (5.3 GW) and the Netherlands (4.2 GW) whilst Spain dropped slightly (7.7 GW).
- In the Americas, both major markets grew - the USA, after a slow 2022 installed **33.2 GW**, and Brazil sustained its dynamic 2022 market to install **11.9 GW**, bringing its cumulative capacity into the Top Ten worldwide.
- **India** had a slightly slower year with **16.6 GW**, once again predominantly in centralised systems. Other Asia-Pacific markets slowed down too, including Australia (3.8 GW), while Korea (3.3 GW) and Japan (6.3 GW) remained steady.

Market growth outside of China reached an honourable 30%, while China's own domestic growth was above 120% which explained the tremendous PV market development.

The number of countries with theoretical penetration rates over 10% double since last year to 18, and whilst smaller populations such as Spain, the Netherlands, Chile and Greece were leaders, more populous countries, including Germany and Japan also passed 10%. While grid

[1] All capacity data in this report is DC, unless specified otherwise. For some countries, this means publishing different values to official data – for example, China's National Energy Administration (NEA) publishes in AC and PVPS applies a conversion ratio from AC to DC. A range of values is often provided to account for uncertainty in AC/DC conversion ratios, in particular with regards to new utility scale capacity in China, where the minimal annual volume considers official China reporting and the maximal annual volume considers a further 42 GW that could have been installed considering the uncertainty surrounding official conversion ratios from AC to DC of Utility scale systems. For many figures, these two values have been represented with full (minimum) and additional shaded (maximum) bars. If no range is specified, compiled data refers to the lower totals with Official China reporting values. See section 3 for more information.

[2] See (1) above

congestion has become an issue, policy measures, technical solutions and storage are already providing workable solutions to enhance PV penetration.

Individual markets remain sensitive to policy support and domestic electricity prices despite competitivity across most market segments in many countries. The ability of local manufacturing projects initiated in previous years to go ahead is uncertain **as significant increases in manufacturing capacity** in China have led to supply outstripping global demand and consequent **record low module prices**. Significant drops in PV module prices due to increased inventory, oversupply and competitive environment among manufacturers caused strain on local manufacturing.

PV played an important role in the reduction of the CO_2 emissions from electricity in 2023, with more than 75% of new renewable capacity installed in 2023, generating nearly 60% of generation from new renewable capacity.

Oversupply of PV modules in 2023 has shed a light on the difficulties to align production and demand in a very versatile environment: while production capacities increased significantly in China, the global demand was framed by constraints in markets such as the USA, India, Korea, and Australia, not exclusively. Growth outside China happened in a limited number of countries. Uneven political support in some markets could also be attributed to the **difficulties to develop local PV manufacturing facilities in an already inundated market**.

International Energy Agency
Photovoltaic Power Systems Programme

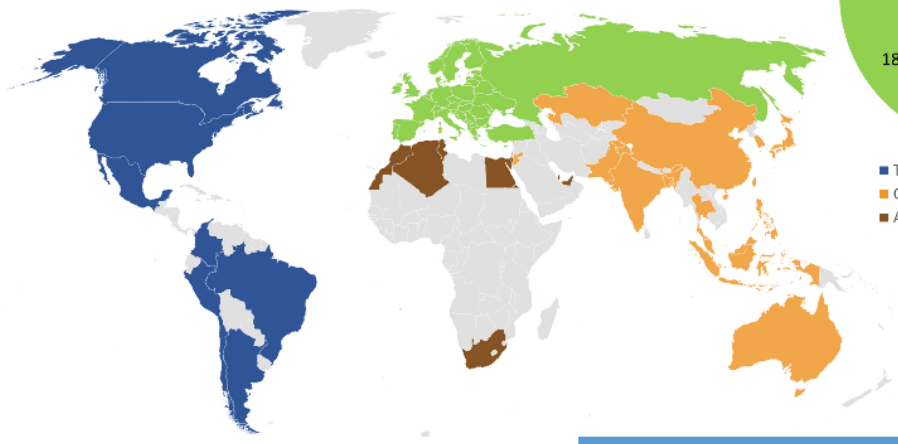
A Snapshot of Global PV Markets

TOP PV MARKETS 2023

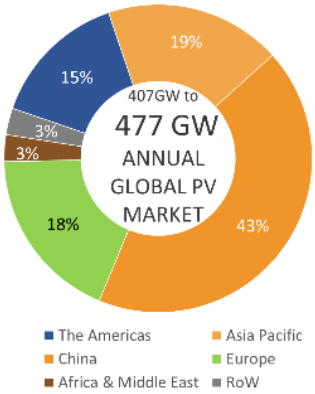
CHINA 235GW to 277 GW

EU 55.8 GW

USA 30 GW



Regional share of cumulative capacity



- 1 624 GW were installed all over the world by the end of 2023
- China is the world's #1 PV market
- 29 countries installed at least 1 GW of PV in 2023
- 19 countries have installed at least 10 GW of cumulative capacity at the end of 2023

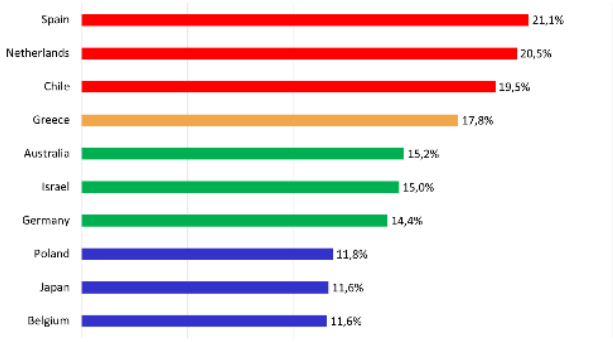
SOLAR PV PER CAPITA 2023 Watt/capita

1st AUSTRALIA 1 331

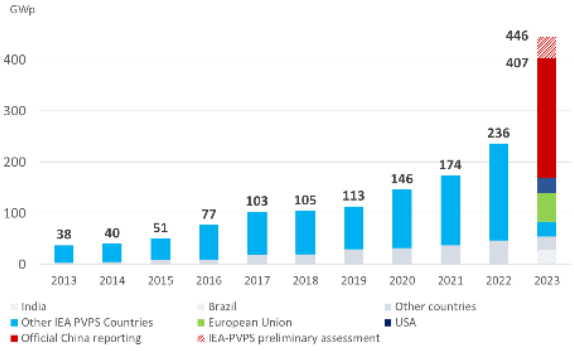
2nd NETHERLANDS 1 268

3rd GERMANY 974

COUNTRIES WITH HIGHEST PV PENETRATION



EVOLUTION OF ANNUAL PV INSTALLATIONS



1 SNAPSHOT OF THE GLOBAL PV MARKET IN 2023

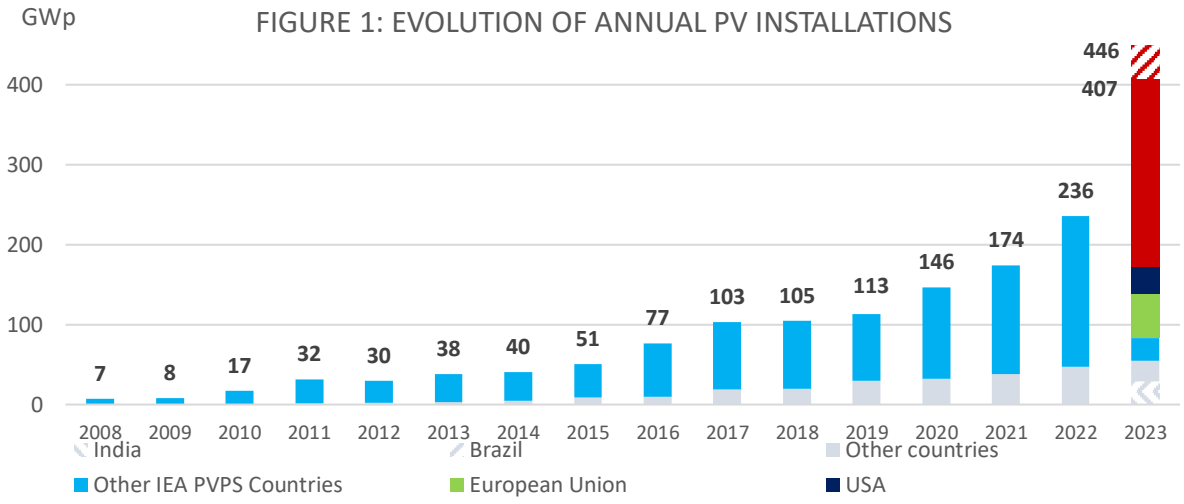
IEA PVPS has distinguished itself throughout the years by **producing unbiased reports** on the **development of PV all over the world**, based on information from official government bodies and reliable industry sources. This 12th edition of the "Snapshot of Global PV Markets" aims at providing **preliminary information** on how the PV market developed in 2023. The 29th edition of the PVPS complete "*Trends in Photovoltaic Applications*" report will be published in Q4 2024.

1.1 Evolution of Annual Installations

It appears that 1 581 GW represents the minimum installed cumulative capacity by the end of 2023, and at least 407.3 GW but perhaps as much as 446 GW[3] of PV systems have been commissioned in the world last year. IEA PVPS countries[4], for whom there is a firm level of certainty in the data, represented 1 342.7 GW (or 85%) of cumulative capacity and 352.8 GW (87%) of annual installations. This year's new installations have nearly doubled those of 2022, up from 236 GW, with a growth rate of over 80% - a rate not seen since 2011.

In 2023, **at least 29 countries installed more than 1 GW**, up from 25 countries in 2022. Nineteen countries (not including the EU) now have more than 10 GW of total cumulative capacity and five have more than 40 GW. China alone represented a minimum of 662 GW followed by the European Union (as EU27) with 268.1 GW, the USA ranks third at 169.5 GW and India has overtaken Japan to take fourth place with 95.3 GW.

FIGURE 1: EVOLUTION OF ANNUAL PV INSTALLATIONS



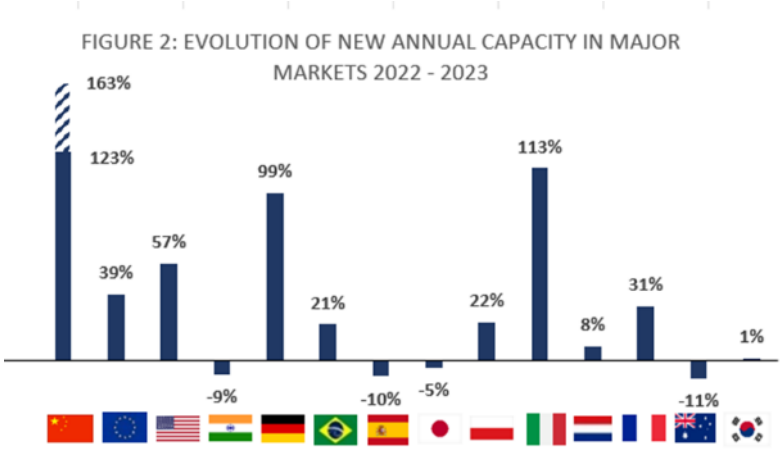
Source: IEA PVPS

[3] The minimal annual volume of 407.3 GW considers official China reporting; the maximal annual volume of 446 GW considers a further 42 GW that could have been installed considering the uncertainty surrounding official conversion ratios from AC to DC of Utility scale systems. For many figures, these two values have been represented with full (minimum) and additional shaded (maximum) bars. If not otherwise specified, compiled data refers to the lower totals with Official China reporting values.

[4] 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.

In the past two years, the market in China has grown so quickly and spectacularly that no other major market has been able to keep up – not even Europe with its own sustained growth (see Figure 2). With continued dynamic growth, China remains the major regional market in 2023 with over 60% of new capacity (compared to 45% in 2022), whilst Europe and the USA account for just 20%, significantly less than in 2022. The 2023 growth in China came mostly from an attempt to absorb the massive production of PV components from local manufacturers, hence 2023 numbers for China are far beyond the authorities targets for PV deployment.

FIGURE 2: EVOLUTION OF NEW ANNUAL CAPACITY IN MAJOR MARKETS 2022 - 2023

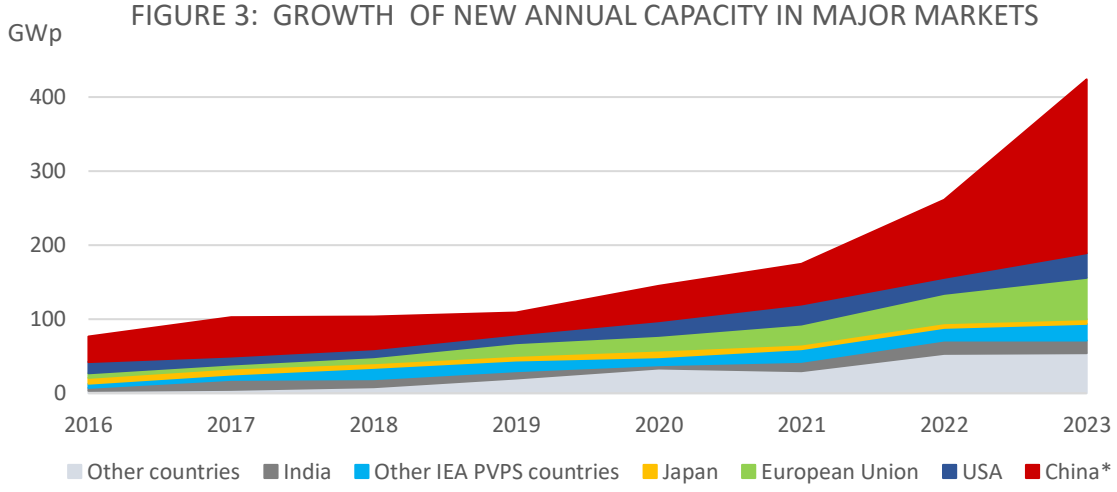


Source: IEA PVPS

With continued dynamic growth, China remains the major regional market in 2023 with approximately 60% of new capacity (compared to 45% in 2022), whilst Europe and the USA account for just over 20%, significantly less than in 2022. The 2023 growth in China came mostly from an attempt to absorb the massive production of PV components from local manufacturers, hence 2023 numbers for China are far beyond the authorities targets for PV deployment.

Over the past 10 years, annual growth rates for new capacity in China have fluctuated according to policy and other constraints, with several years of negative growth and several other years of growth rates over 100% (including this year's over 125%). The global market excluding China has had a steadier evolution with growth rates of 10% to 37% over this period. However, with the new size of the Chinese market, the steadying influence of other markets will diminish significantly.

FIGURE 3: GROWTH OF NEW ANNUAL CAPACITY IN MAJOR MARKETS



**Official China reporting*

Source: IEA PVPS

1.2 Impact of the Ukraine War and over-capacity in manufacturing

From early 2022, the political tensions in Europe and resulting reduced gas acquisitions had resulted in several high peaks in wholesale and domestic electricity prices, not just in Europe but across a range of other countries as far as Australia - although by 2023 these prices have stabilised somewhat. In Europe, 2023 spot prices were in the 50€/MWh to 100€/MWh range, down from 2022 peaks over 300€/MWh to 500€/MWh. Despite the reduction in electricity prices, they remain higher than what many PV plants can provide, leaving the door open to PV competitiveness on electricity markets, independently of the record-low prices for PV modules seen from mid-2023.

In 2023, the continued increase in manufacturing capacity largely outstripped the market's ability to absorb new module availability. By the end of 2022, module stocks had already reached a volume above that of the European and USA installed markets combined, and 2023 only saw an acceleration of this trend. There is now an estimated 150 GW of module stock. Compounding the effects of increased manufacturing capacity leading to large inventories, the transition of the mainstream industry from PERC to TOPCon (amongst other n-type technologies), and an important but not sufficient global market growth. This has resulted in massive price drops along the value chain.

Domestic demand in China, pulled by favourable local policies, has ensured that a part of the oversupply has been absorbed. However, the uptake hasn't been able to compensate for the tremendous oversupply alone, and the honourable but insufficient growth of global PV markets has led to a significant drop in PV module market prices. At the beginning of 2024, several Chinese manufacturers that remained largely viable in 2023, called for urgent measures in China to avoid the entire industry collapsing, as did smaller manufacturers outside China. Increasing controversy surrounding the very low late 2023 module prices on the international market has led to industry discussion on unsustainable price dumping.

The low prices and large inventories have been particularly impacting on the slow development of local manufacturing projects outside of China and South-East Asia, where competitiveness was already considered hard to reach. This has comforted policymakers advocating for trade barriers and additional incentives for local manufacturing especially in the USA and India, and a vivid debate in the EU.

1.3 Focus on the Top Markets in 2023

The Chinese market grew at a very high rate of over 125% and installed a minimum of 235 GW (official China reporting) up to a possible 277 GW in 2023 (up from 106 GW in 2022 and 55 GW in 2021). With 55.8 GW of annual installations, the European Union ranked second, followed by the USA at 33.2 GW (back to strong volumes after a slower 2022) followed by India with a slightly contracted market of 16.6 GW. Very strong growth in Germany with 14.3 GW saw the country leapfrog a still strong Brazil (11.9 GW) into fourth place.

TABLE 1: TOP 10 COUNTRIES FOR ANNUAL AND CUMULATIVE INSTALLED CAPACITY IN 2023

FOR ANNUAL INSTALLED CAPACITY				FOR CUMULATIVE CAPACITY			
1		China	235.5 GW*	1		China	662.0 GW*
(2)		*European Union*	55.8 GW	*(2)*		*European Union*	268.1 GW
2		United States	33.2 GW	2		United States	169.5 GW
3		India	16.6 GW	3		India	95.3 GW
4		Germany	14.3 GW	4		Japan	91.4 GW
5		Brazil	11.9 GW	5		Germany	81.6 GW
6		Spain	7.7 GW	6		Spain	37.6 GW
7		Japan	6.3 GW	7		Brazil	35.5 GW
8		Poland	6.0 GW	8		Australia	34.6 GW
9		Italy	5.3 GW	9		Italy	30.3 GW
10		Netherlands	4.2 GW	10		Korea	27.8 GW

Note: The European Union grouped 27 European countries in 2023, out of which Germany, Spain, Poland, Italy and the Netherlands also appear in the Top Ten, either for the annual installed capacity or the cumulative installed capacity. The European Commission is a member of IEA-PVPS through its Joint Research Centre (EU-JRC).
*Official China reporting capacity, below IEA-PVPS preliminary assessment of 277 GW / 704 GW

Source: IEA PVPS

To reach the Top Ten for new capacity in 2023, countries needed to install at least 4.2 GW of PV systems (compared to 3.9 GW in 2022 and just 1.5 GW back in 2018). Australia gave way to the Netherlands as its market decreased for the 2nd consecutive year. Within the Top Ten of total cumulative installed capacities there is an increased gap of 44 GW between fifth placed Germany and sixth placed Spain, as the bottom of the table failed to meet the dynamic markets of those higher up the table. Japan's stable market is not sufficient to keep its place as it is overtaken by India.

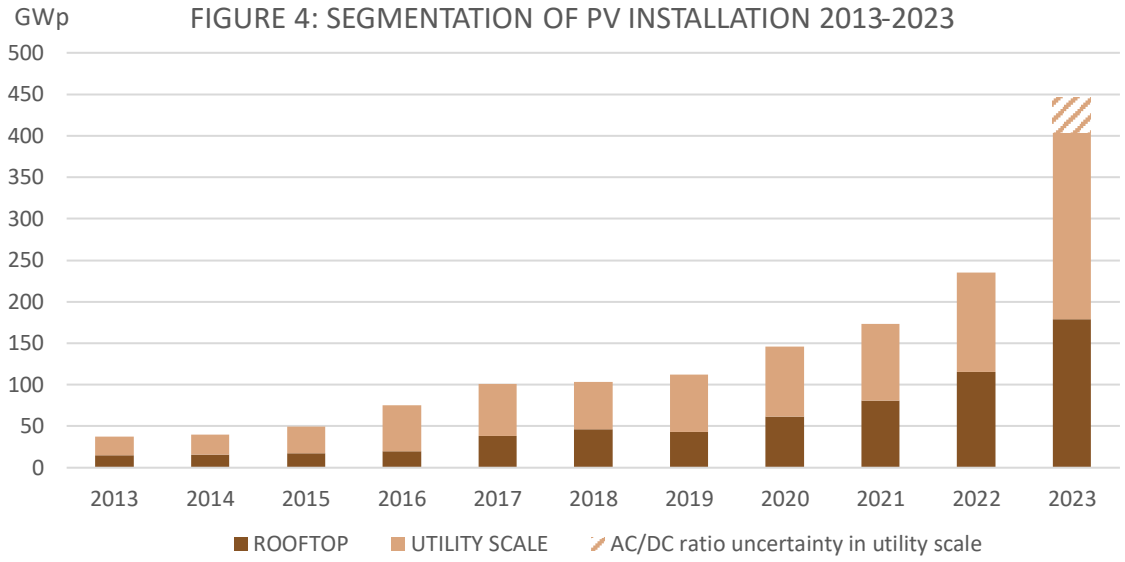
1.4 Market Segmentation

Both rooftop and utility scale segments grew in 2023. Market segments were reasonably balanced, with approximately 45% of new capacity on rooftops – although data uncertainty in converting utility scale AC capacity to DC capacity in China is such that this distribution is uncertain. The share of the rooftop segment had been growing continuously since 2018 as markets open in new countries, decreasing costs and higher electricity consumption costs make it more accessible for residential and commercial investors, with both dominant market shares and notable volumes (> 4 GW) in Germany, Brazil, Poland and Italy, and to a lesser extent (> 2.5 GW) in the Netherlands, Australia and France. In other countries such as the USA, India and Spain, utility scale systems cover more than 65% of the local market. China has fluctuated yearly, and this year's majority of utility scale systems may not be repeated next year.

On both segments **new applications are in growth**; from BIPV in the rooftop segment to utility scale floating PV.

Still marginal but growing, agrivoltaic projects and BIPV are as yet hard to quantify, as are VIPV/VAPV[5] volumes (PV integrated in vehicles), although they are expected to develop well in the coming years. Technological evolutions, such as bifacial PV or the new module technologies will also impact the development of these new market segments.

FIGURE 4: SEGMENTATION OF PV INSTALLATION 2013-2023



Source: IEA PVPS, Becquerel Institute

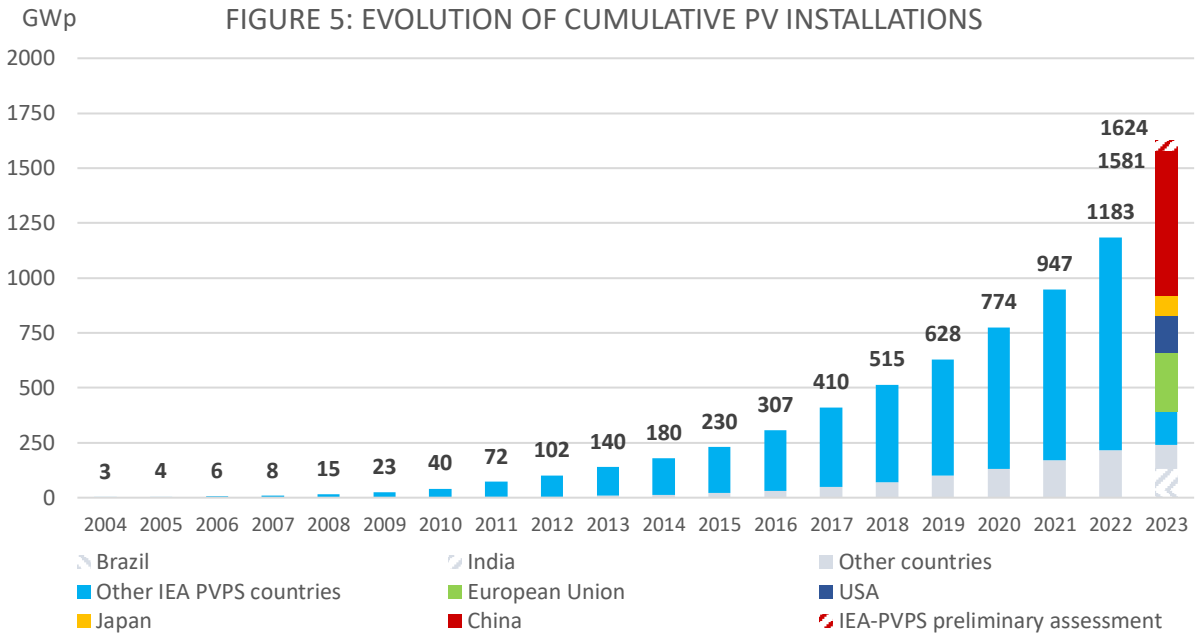
2 CUMULATIVE INSTALLED CAPACITY IN THE WORLD

In 2023 the **global cumulative installed capacity reached 1.6 TW**, reaching an estimated 1581 GW to 1 624 GW, as shown in Figure 5. Most remarkably, the new annual capacity installed in China in 2023 (235 GW - Official China reporting to 277 GW – IEA-PVPS preliminary assessment) is just over of the total cumulative installed capacity in Europe (314.7 GW, of which 268.1 GW is in the EU). Cumulative capacity hit the top of the 20% to 35% growth rate range of the past 10 years.

As indicated in Table 1, the top 5 countries from China down to India and then Germany (81.6 GW) have at least 40 GW more than the next countries and have widened the gap by more than 10 GW since last year. The next group of countries with between 25 GW and 40 GW, found across most continents, is only just trailed by France (23.6 GW) and the Netherlands (22.4 GW).

[5] BIPV – Building Integrated PV; VIPV – Vehicle Integrated PV; VAPV - Vehicle Added PV

FIGURE 5: EVOLUTION OF CUMULATIVE PV INSTALLATIONS



Source: IEA PVPS

2.1 Evolution of Regional Share of PV Installations

The majority share of global PV installations is held by Asia-Pacific and has once again increased in 2023, rising to over 60%, with a cumulative installed capacity of at least 947 GW. A closer look shows us that it is China, not Asia-Pacific as a whole, that has increased its share (see Figures 6A and 6B). Excluding China, the three other major regional markets – the remainder of Asia-Pacific, Europe and the Americas - are all roughly equivalent, the first two holding 19% and the latter 15% of global cumulative PV installations.

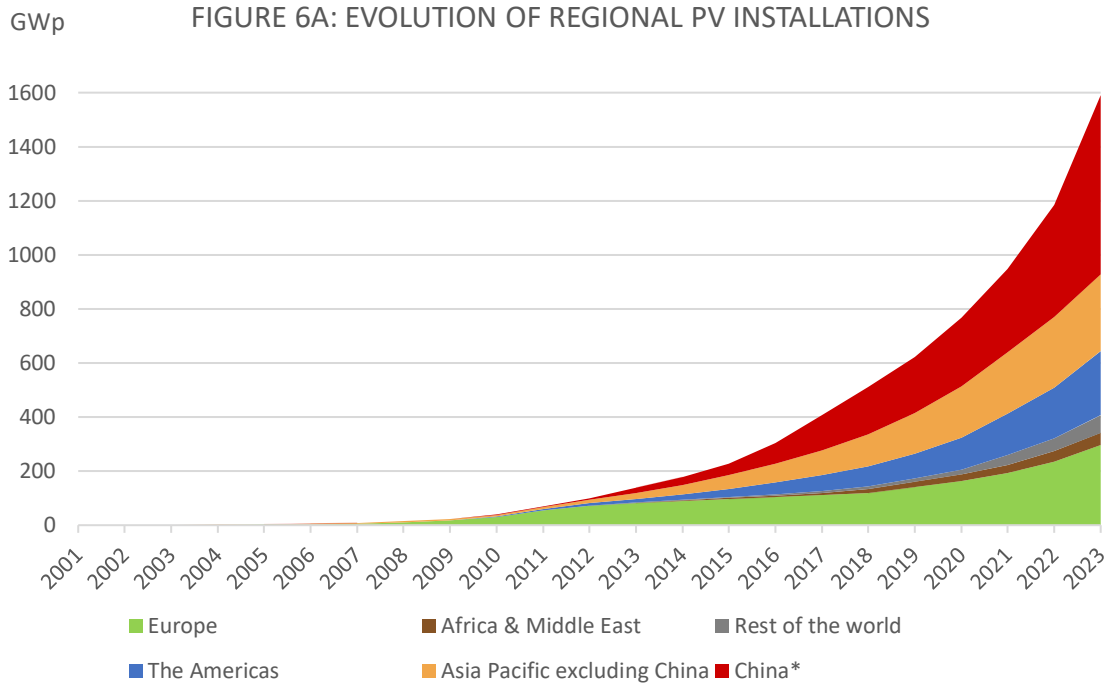
The **rest of Asia-Pacific's markets** were generally in slight contraction or steady over 2023 compared to 2022. The Japanese market has varied from 6 GW to 10 GW a year over the past 10 years now and seems to be finding stability at about 6.3 GW, reaching a cumulative capacity 91.4 GW. With a similar cumulative capacity, India has had a more volatile market, ranging from under 1 GW in 2014 up to 2022's 18.6 GW. Hurdles to steady growth include administrative procedures, grid access and financing. With very ambitious local manufacturing and development targets, India is still expected to take a leading role. The Australian market was a promisingly steady 4 GW to 5 GW for 5 years but has dropped below 4 GW this year, whilst in the same period Korea has bounced between 2.6 GW and 5 GW, settling at just over 3 GW the past 2 years. These two countries both have a cumulative capacity of between 25 GW and 35 GW. The other national markets with any significant capacity in Asia-Pacific are Vietnam (whose fragile grid stopped new capacity after two multi-GW years in 2019/2020) and Taiwan who may hit 3 GW in 2023. Whilst each country has cited specific reasons for the sluggish markets, a more fundamental underlying problem remains.

Across the **European regional market** there was growth in annual capacity in nearly all markets, riding on the increased competitiveness of PV with respect to high electricity prices from the consequences of the Ukraine conflict, but also urgent political mandates to increase

energy autonomy and renewable energy production. The main contributor is still Germany (adding 14.3 GW to reach 81.6 GW), riding on strong political motivation, followed by two countries with over 30 GW cumulative capacity: Spain (down from 8.5 GW in 2022 to 7.7 GW in 2023) and Italy (over 100% growth to 5.3 GW new capacity). These are followed by France at 23.6 GW (+ 3.9 GW), the Netherlands at 22.4 GW (+ 4.2 GW) and Poland catching up (+ 6 GW to 18.5 GW). Nearly a dozen other European countries installed more than 1 GW in 2023.

The **Americas regional market** is largely driven by the USA, returning to volumes similar to 2021 after a slower 2022 by adding 33.2 GW to reach 169.5 GW or over 70% of cumulative capacity in the region. However, the dynamic growth in Brazil has continued, adding 11.9 GW (up from 9.9 GW in 2022) to reach 35.5 GW. Chile (up 1.3 GW to 9.2 GW cumulative capacity) may reach double digits in 2024, whilst Canada (7.3 GW cumulative capacity) could in the next 3 years.

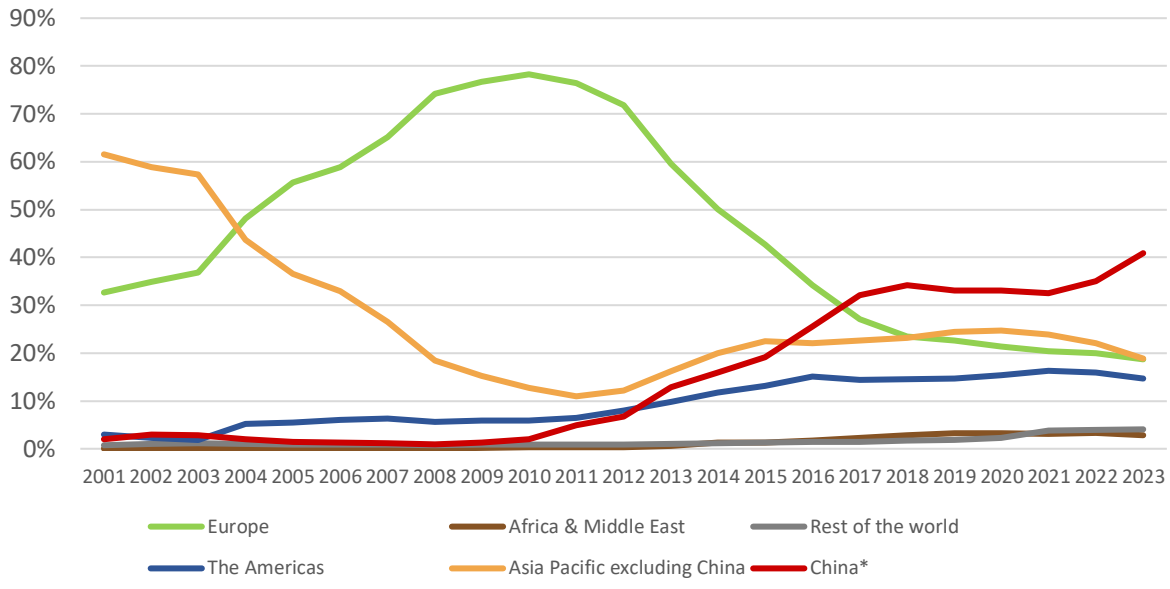
FIGURE 6A: EVOLUTION OF REGIONAL PV INSTALLATIONS



**Official China reporting*

Source: IEA PVPS

FIGURE 6B: EVOLUTION OF REGIONAL SHARE OF GLOBAL MARKET



**Official China reporting*

Source: IEA PVPS

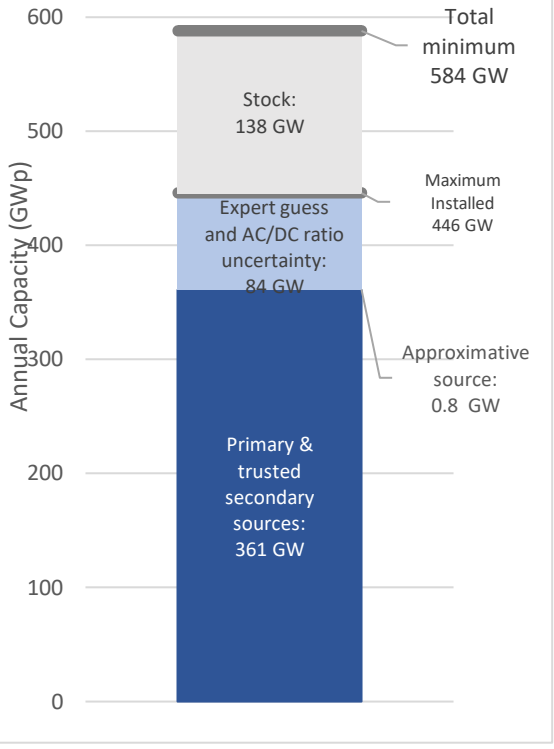
In the Middle East and Africa, South Africa installed nearly 3 GW and was responsible for the bulk of new capacity, with less than an estimated 700 MW elsewhere. This is despite a significant volume of projects announced from the past years – the ability of the region to see projects into construction is still to be proven. For example, Egypt had just over 300 MW of new capacity in 2023, with 700 MW in construction but an announced pipeline of over 11 GW.

2.2 Limits of Reporting Conventions

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. **Converting AC to DC power**, particularly on data sets covering a wide geographical area, is subject to a rather large uncertainty, as is demonstrated with **China data** – Official reporting of Utility scale is in AC power, China experts use a 1.15 conversion ratio whilst others use up to 1.5. With a lack of hard data on existing systems, these ratios are built on limited surveys and standard dimensioning practices.

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.

FIGURE 7: COMMISSIONED AND STOCKED VOLUMES 2023



Source: IEA-PVPS

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.

To understand the state of global markets, it is necessary to have a knowledge of current **module inventories** – as manufacturing capacity ramped up quickly through 2022 and 2023, supply outstripped demand and prices plunged as manufacturers looked to avoid full warehouses. However, markets were not able to follow the rhythm of manufacturing capacity upgrades, leaving significant volumes in stock. Stocked volumes have been determined based on the difference between manufactured, exported and commissioned volumes, and have been integrated here. Inventories have been calculated based on known manufacturing and export volumes and analysed with regards to installed volumes. This data has been incorporated in Figure 7 to improve market visibility.

2.3 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 replace some decommissioned capacity but also generally increase operational capacity, as the repowered capacity is higher than the initial plant capacity due to PV module efficiency improvements.

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

Repowering[6] is still relatively unusual given the age of the oldest installations, but it is expected to increase in the near future – the serial defects of backsheets with specific materials, 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 encourage repowering. Recycling numbers can provide a glimpse of what is happening with regards to repowering and decommissioning in countries where recycling schemes are active, however 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 aging PV systems.

IEA PVPS Report:

Data Model and Data Acquisition for PV Registration Schemes and Grid Connection – Best Practice and Recommendations.

Available at https://iea-pvps.org/

2.4 AC or DC Numbers?

By convention, the numbers reported refer to the nominal power of PV systems installed. These are expressed in W (or W_p). Some countries report the power output of the PV inverter (the device converting DC power from the PV system into AC electricity compatible with standard electricity networks) or the grid connection power level. The difference between the standard DC power (in W_p) and the AC power can range from as little as 5% (conversion losses, inverter set at the DC level) to as much as 60%. For instance, some grid regulations limit injections to as low as 70% of the peak power from the residential PV systems installed in the last years. Most utility-scale plants built in 2023 have an AC-DC ratio between 1.1 and 1.5. For some countries, **numbers indicated in this report have been transformed to DC numbers to maintain the coherency of the overall report.**

In general, IEA PVPS recommends registering PV systems with both the DC power and the AC value. DC power allows a reliable calculation of the energy production whilst AC power allows a better understanding of the theoretical maximum power output of the PV fleet. More information about recommendations to properly register PV plants can be found in the Data Model and Data Acquisition report (see link and QR code above).

[6] Repowering is the practice of replacing part or all of the modules of an existing system with newer, more efficient modules. In this process, the overall peak power of the system may be increased.

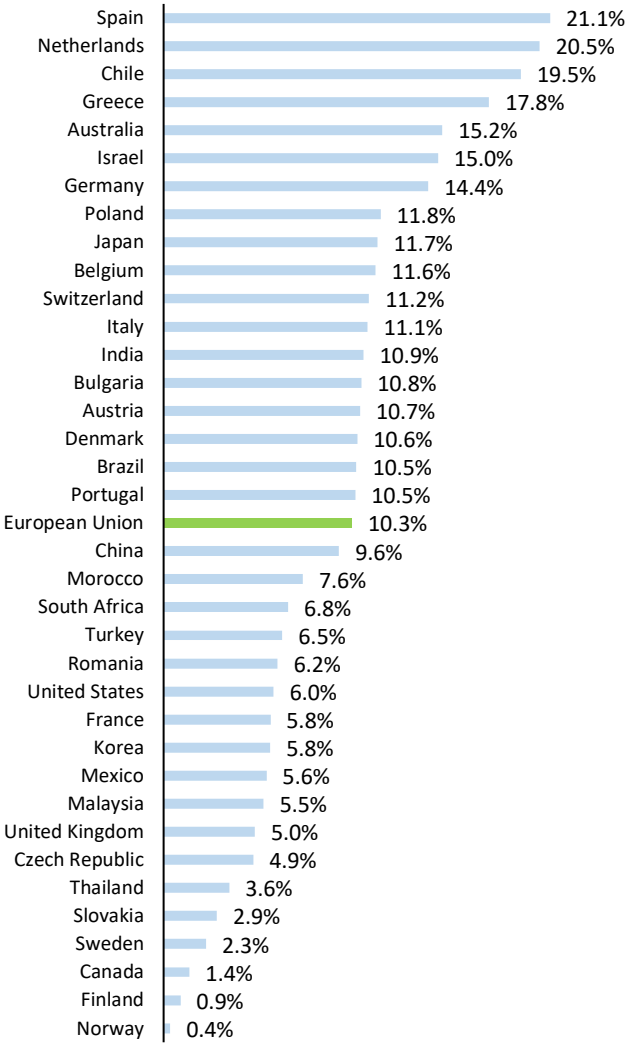
3 ELECTRICITY PRODUCTION FROM PV

Figure 8 shows how PV theoretically could contribute to meet the electricity demand in key IEA PVPS countries and other major markets. It gives a comparative view of the **contribution the cumulative installed capacity of PV at the end of 2023 could have to 2024 electricity consumption**.

PV generation is easy to measure for an individual system but more complex for an entire country. 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 on buildings may not be at optimum orientation or have partial shading. Electricity self-consumed by prosumers is generally not metered.

Here, generation is based on the theoretical electricity production from all installed PV, calculated based on cumulative PV capacity at the end of 2023, close to optimum siting, orientation, and yearly weather conditions, and includes utility scale, self-consumption and even off grid system generation. Numbers may differ from official PV production numbers in some countries. It is evidently an optimistic evaluation, and should be considered as indicative, providing a reliable estimation for comparison between countries and does not replace official data.

FIGURE 8: THEORETICAL PV PENETRATION 2023



Electricity consumption based on official data, however sources of uncertainty in the PV penetration rate from consumption include how different countries report self-consumed electricity (adding, or not, as the case may be, this electricity to official consumption data) – efforts have been made to rectify this, however as reporting is varied it is disparate.

There are now 18 countries with an estimated penetration rate over 10% (up from 9 in 2022): Spain, the Netherlands, Chile and Greece at over 17%, followed by Australia, Israel and Germany over 14%. With increased rates of PV installed, many countries have added 2 percentage points or more compared to 2022. The **increasingly large volumes of installed capacity are making a tangible contribution to electricity consumption around the world**. The two principal PV markets, China and the Europe Union, demonstrate this with approximately 10% each. In total, **PV contribution amounts to over 8% of the electricity demand in the world.**

4 POLICY & MARKETS TRENDS

4.1 Policy Trends

Public policies with regards to photovoltaics tend to change as governments seek to promote solar or react to changing costs to investors or even state aid programs.

Increased competitivity has been a driver for many policy changes, in particular with regards to shifting towards prosumer policies (see below, section 4.3). Across Europe and in other countries, where once building regulations encouraged solar, it is becoming near mandatory or a more common requirement to increase energy autonomy (France, mandatory solar on larger buildings and car parks or Korea, zero energy building regulations). In parallel, policies to support the development of PPA have been tested (Malaysia, France).

Some noticeable policy changes have demonstrated the impact these changes can have on national markets. Examples include the rush of commissioning before the end of net metering in Wallonia, Belgium, installation rush caused by net-metering rule change in California, USA to another similar rush in 2022 in Denmark to beat changes in utility grid connection fees that lead to reduced interest in utility scale projects in 2023, or the numerous policies and actions put in place in 2023 in China to support the development of the Chinese industry and market.

Policy support for batteries has also advanced, especially in countries with grid congestion, high penetration rates or high electricity costs. Policies and market design facilitating storage coupled with distributed and/or utility scale solar now exist in Austria, Australia, China, Germany, Italy, Japan, to name a few). In particular, mandatory coupling of storage with solar in China has led to record volumes globally.

As in 2022, simplification or rationalisation of permitting and environmental procedures has continued (China, France, Italy), having been identified as a key lever in facilitating projects but also with respect to improving wider social acceptance of utility scale plants.

Policies to support local manufacturing, engaged in 2022 or 2023 were slowly solidified, although final implementation is difficult to achieve (including the U.S. Inflation Reduction Act (IRA) and European countries policies), although the ability of these policies to support the real emergence of local manufacturing is in question since the price plunge of new modules has led to a highly competitive market for manufacturers.

A number of countries are currently revising solar targets within national planning or strategic documents (France, Japan, Portugal, Spain), or have set them for the first time (Austria, Norway).

4.2 Competitive Tenders & Merchant PV

Tenders continued to be used, although increasingly PPA (power purchase agreements) and cPPA (corporate PPA, with a final commercial or industrial consumer) or even merchant PV (electricity sold on the market) are forging ahead, not only due to the increasing competitivity of PV but also because of the efforts by commercial entities to keep control of future electricity costs through stable long-term contracts that meet increasingly stringent social and environmental responsibility standards. Whilst through 2022 the peaking electricity costs were a strong motivator for immediate investment, the impact of fluctuations was also sufficient to push consumers to look towards more previsible supply costs and continue investing. The

number of PPAs signed has increased through 2023, even in those markets where PPAs were sold at much lower prices in 2023 than 2022 (Europe, for example).

Tenders continue to run, and indeed have had more success in terms of subscribers in 2023 in some countries than in 2022 as electricity markets calmed (France, for example). Also, tenders run in 2020 or 2021 have not yet finished construction so tender-based systems will continue be commissioned in the coming years, for example Portugal, France. Overall, utility scale systems continue to grow in major markets, with inflation and increased financing costs counterbalanced by lower modules costs – although the protected regional market of the USA did not benefit from lower prices to the same extent as the rest of the world.

Tenders can be exclusively cost based or integrated multiple factors such as land use, carbon footprint or geographical location. As concerns over the concentration of supply chains in China evolve, some governments have looked to tender mechanisms to encourage local content, although trade rules make this a complex undertaking.

4.3 Prosumers Policies

Prosumers (entities that are both producers and consumers of energy) are becoming more **active market drivers around the world** as electricity consumption prices go up and PV penetration rates increase, improving understanding of and access to prosumer policies.

In reaction to different factors, including increased competitivity, direct and indirect support mechanisms are being adapted in some countries to further promote prosumer policies: individual self-consumption, collective self-consumption and/or energy communities (Austria, Switzerland, Italy, France.

Prosumer excess generation is generally paid for through net metering (generally in emerging markets), or net billing in more experienced markets with smart or communicating meters. The move away from net metering is continuing as PV costs go down (Wallonia, Belgium, where net metering is no longer offered in 2024), but also USA where net metering is being replaced by net billing. Remuneration rates vary and can be low to dissuade injections into the grid or on the contrary benefit from feed in tariffs or market premiums. These remuneration rates can be associated with a range of different constraints, from capacity limits to mandatory building integration or carbon footprints.

Collective self-consumption – where one or several PV producers (even utility-scale plants) supply one or more consumers in the same building or within a small geographical perimeter with reduced use of the public grid - continues to grow, although the wide range of mechanisms used can make it difficult to compare between countries. The use of self-consumption in collective buildings is growing (many EU countries), whilst other models such as distributed (or virtual) self-consumption are becoming more common. These models have in common that they allow a higher rate of self-consumption than if only one consumer is associated, and are increasingly seen as a market substitute, allowing small scale generators to sell directly to consumers without having to become commercial operators, an often complex process.

In the Clean energy for all Europeans package, the European Union introduced the concept of Renewable Energy Communities (REC) and of 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. This concept of energy communities is likely to expand existing PV market segments and to allow

cost reductions for consumers not able to invest in a solar installation themselves, although the transcription into local law is slow.

4.4 Grid Integration and Access

With increasingly high penetration rates of PV in more and more countries, transmission and distribution system operators are having to **anticipate and more actively manage PV**. In some smaller regions (Australian states, in particular) penetration rates are so high that **rooftop solar has provided 100% of power over several hours** multiple times. These regions are actively trialling technologies and policies that will be adapted in other regions as penetration rates increase. Grid congestion and longer delays for grid connection have not allowed local markets to develop to full potential (USA in 2022, Austria, Japan ongoing).

How the cost burden of managing, reinforcing and renewing grid infrastructure is shared has become one of the more sensitive topics. Increased behind-the-meter generation can reduce revenue collected on consumption, whilst midday exports can congest grids and impact grid balancing. As penetration rates increase, **new governance models compatible with market and climate policy driven deployment targets** will need to be established to ensure PV can be smoothly deployed.

4.5 Local Manufacturing Policies

The different disruptions of 2020 to 2022 (covid, geopolitical tensions around the world and pollution episodes in China) have highlighted the **fragility of the PV value chain**, at a time when governments are looking to increase generation from PV. Supporting local manufacturing at various steps of the PV value chain has become important in different regions, **pushing numerous governments to support local manufacturing** through policies, subsidies and regulation – notable examples include the USA's Inflation Reduction Act (IRA).

Local manufacturing initiatives in Europe, the USA, India, Morocco or Saudi Arabia have continued to be discussed, however given the scope of some of the intentions, it is a slow process; in 2023 there was still elements of the Inflation Reduction Act (IRA) in the USA to be regulated. Despite this, there are more than 250 GW of announced manufacturing capacity across 80 new facilities or expansions in the USA. In Europe, the EU Innovation Fund has planned to finance new manufacturing projects, and have announced support for new projects in Spain, Germany, Sweden and capacity expansion in Norway in 2022, and whilst new manufacturing projects were also announced in 2023, by early 2024, the low module prices have left many doubts as to the short term viability of these projects with some manufacturers indicating the EU framework was not sufficient for them to continue in Europe. In 2024, the announcement of the final Net Zero Energy Act in the EU has increased the hopes of seeing a local industry developing: the NZIA is written to offer options for European countries to dedicate parts of the PV market to local manufacturers through specific pre-conditions in tenders, public procurement and additional measures.

4.6 2024 Market Perspectives in IEA PVPS Countries

Most IEA PVPS member countries expect continued steady volumes or small growth in 2024, although there are some exceptions where policy changes (Belgium), increased inflation and interest rates (Sweden) and grid congestion and new fees (Austria, Denmark) could lead to

market slowdowns. The Chinese market is one of these exceptions, with an expected volume of between 190 GW_{AC} and 220 GW_{AC}, below 2023 volumes but still well above 2022 levels.

Other markets are expected to grow, or maintain steady volumes, from changes in policy, new incentives (Switzerland) or simplifications for self-consumption, building regulations pushing solar (Korea) or simply continued competitiveness of PV with investment tax credit under IRA (USA). Projects in development having passed permitting procedures represent a considerable pipeline in many countries (Spain, 30 GW permitted in 2023, France with 26 GW and USA with 30 to 40 GW in the grid connection/government queues).

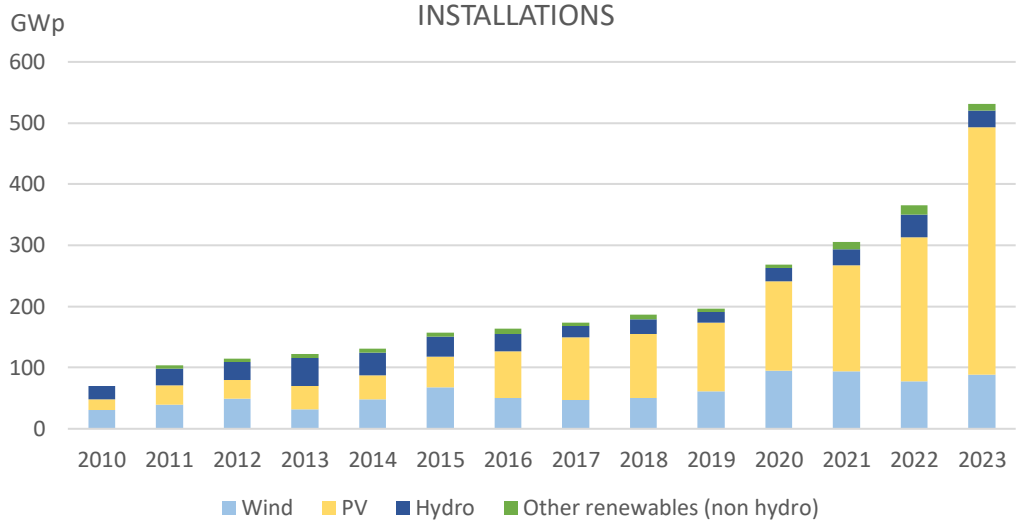
High interest rates in numerous countries have weakened the competitiveness of PV installations while the blow to many manufacturing projects due to extremely unsustainable low module prices are taking a toll on the willingness to develop PV in several key markets, USA and India to mention just these two.

5 PV IN THE BROADER ENERGY TRANSITION

5.1 PV and Other Renewable Energy Evolutions

PV is playing a major role in the energy transition – and in 2023 represented more than **75% of all new renewable electricity technologies**, thanks to its consistent cost reduction, technical performance and accessibility, and generally faster permitting procedures than wind or hydro. As manufactured and installed volumes increase, so do competitiveness, workforce competency and investor confidence, allowing solar to be adopted as a safe, mature technology investment.

FIGURE 9: EVOLUTION OF ANNUAL RENEWABLE ENERGY INSTALLATIONS



Sources: compilation of IEA PVPS, IHA, BNEF, GWEC, IRENA and estimations for 2023

In 2023, solar PV generated just under 60% of the total renewable electricity production from new production assets despite being nearly 80% of new capacity. The difference between capacity and generation is due to the different capacity factors of renewable technologies, with solar having the lowest of all.

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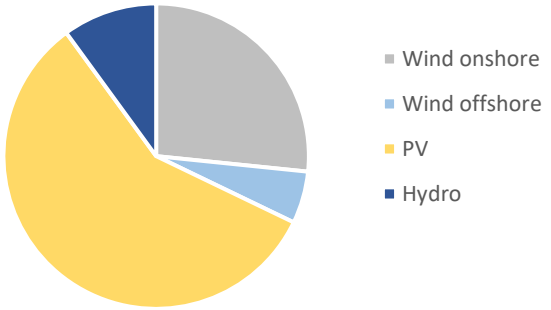
Whereas biomass installations can virtually produce all day and all year-round, wind and PV installations' outputs strongly depend on the available resources that can vary locally – for example, with more consistent winds, offshore wind power has a higher capacity factor than onshore wind, and dependant on sunlight, PV can only produce during daylight hours.

FIGURE 10: ELECTRICITY PRODUCTION OF THE RENEWABLE ENERGY CAPACITY INSTALLED IN 2023



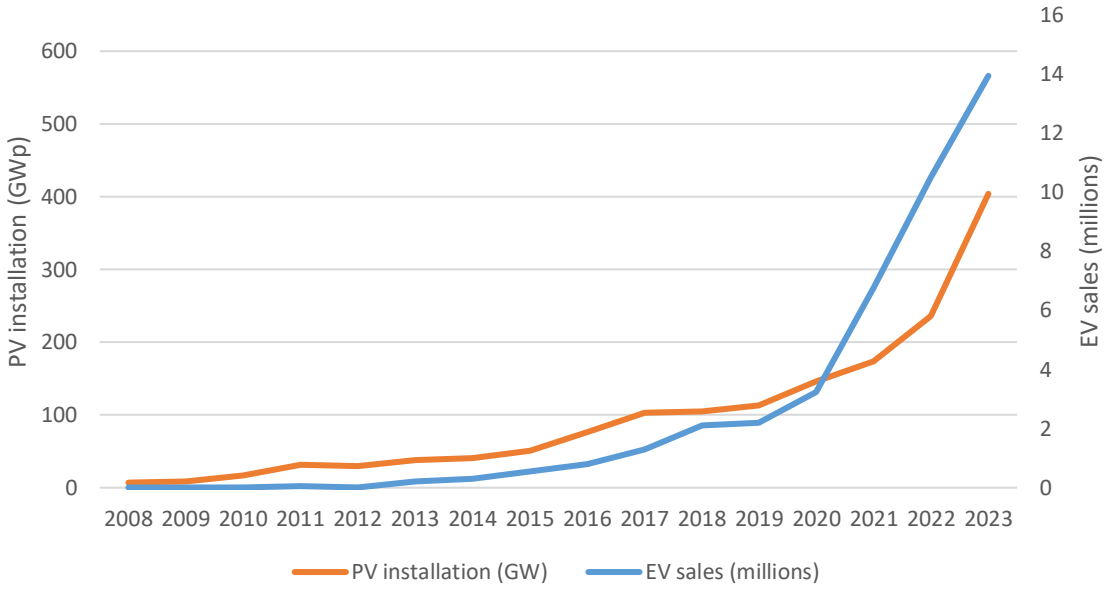
Sources: compilation of IEA PVPS, IHA, BNEF, GWEC, IRENA and estimations for 2023

5.2 PV Fostering Development of a Cleaner Energy System

PV provides direct and immediate carbon emission economies as it replaces or displaces fossil fuel generation. Anticipating large amounts of cost competitive green electricity from PV soon, an increasing number of research, pre-industrial and commercial investments are being made to leverage the future electricity production for hydrogen or other molecules such as ammonia seen by many as technologies with a potential to tackle climate change.

As the sector with the most growth in CO2 emissions in 2023 – despite record electrification - transport is a key factor worldwide. The electrification of transport is accelerating, and the increased studies and practical examples of charging EVs during peak load for grid management is being enabled by smart metering, whilst concepts such as virtual self-consumption, dependant on metering and secure exchange frameworks remain an attractive possibility to provide a framework for EVs as mobile storage for excess PV generation. With **13.9 million EVs sold in 2023 (+33% on 2022 worldwide)**, the rate of growth remains on par with that of PV outside of China. Whilst only 1 in 10 new cars sold in America is electric, in Europe it is 1 in 5 and in China it is 1 in 3. If Germany is excluded (contracted market due to subsidy changes), growth in Europe was on par with that of China at over 30%, but still behind North America.

FIGURE 11: EVOLUTION OF EV AND PV ANNUAL GROWTH



Source : IEA PVPS & EV Volumes

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