Technology Collaboration Programme
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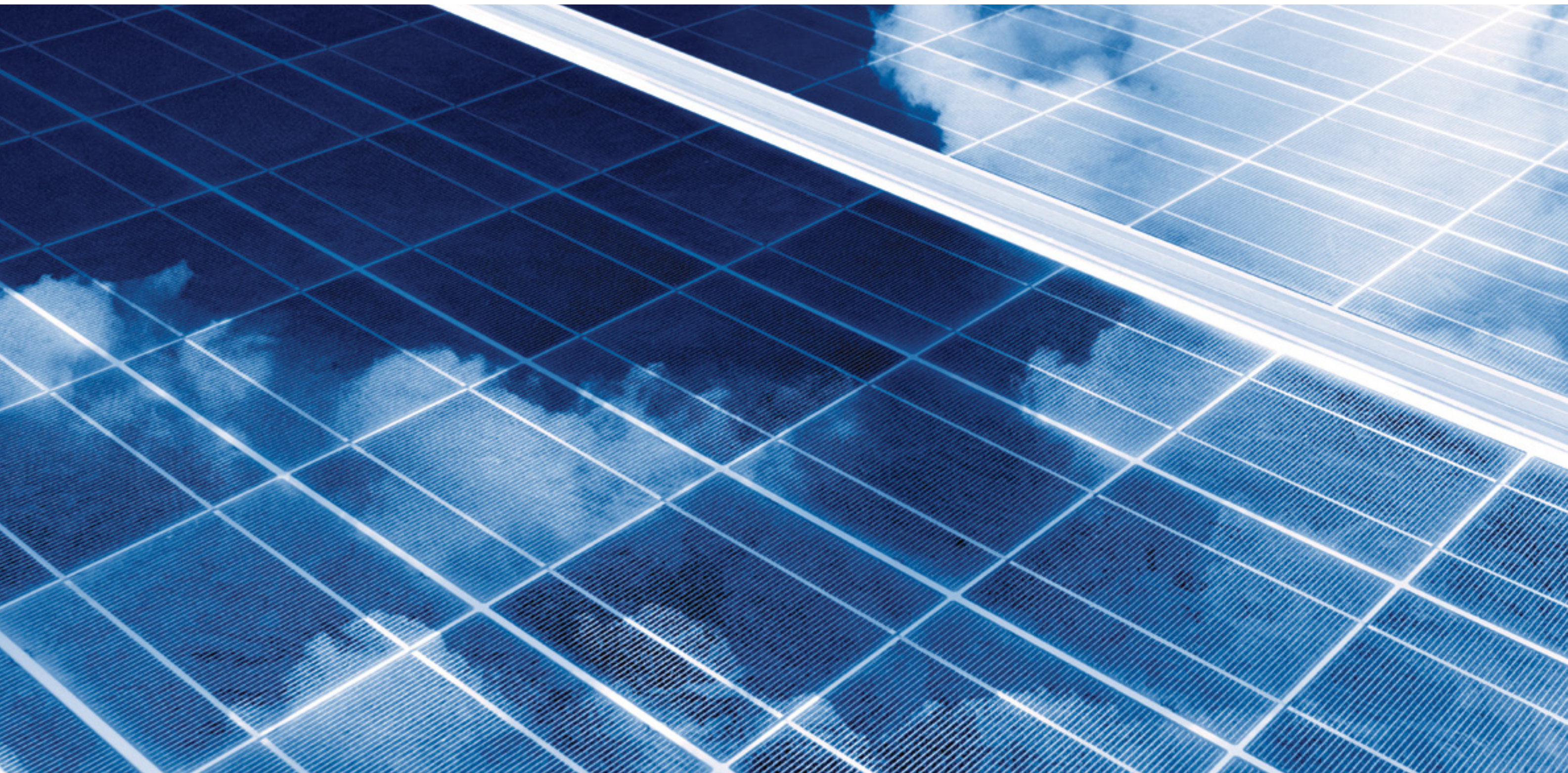
International Energy Agency
Photovoltaic Power Systems Programme



Task 1 Strategic PV Analysis and Outreach

PVPS

TRENDS IN PHOTOVOLTAIC APPLICATIONS 2022

REPORT IEA PVPS T1-43:2022

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 are Australia, Austria, 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, Solar Power Europe, the Smart Electric Power Alliance (SEPA), the Solar Energy Industries Association and the Solar Energy Research Institute of Singapore are also members.

Visit us at: www.iea-pvps.org

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REPORT SCOPE AND OBJECTIVES

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

This report is prepared to assist those who are responsible for developing the strategies of businesses and public authorities, and to support the development of medium-term plans for electricity utilities and other providers of energy services. It also provides guidance to government officials responsible for setting energy policy and preparing national energy plans. The scope of the report is limited to PV applications with a rated power of 40 W or more. National data supplied are as accurate as possible at the time of publication. Data accuracy on production levels and system prices varies, depending on the willingness of the relevant national PV industry to provide data. This report presents the results of the 25th international survey. It provides an overview of PV power systems applications, markets and production in the reporting countries and elsewhere at the end of 2021 and analyses trends in the implementation of PV power systems between 1992 and 2021. 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. The report authors also gratefully acknowledge special support of Eddy Blokken from SERIS.

FOREWORD

The annual PV market reached 175 GW worldwide in 2021. While the world was facing the second year of a pandemic and despite the end-of-year disruptions in Asia, the photovoltaic market continued growing. Without these drawbacks, it probably could have reached 200 GW. This is an exceptional result: 945,7 GW of PV power plants were producing electricity worldwide at the end of the year, of which around 70% have been installed during the last five years. Over the years, an increasing number of markets have started contributing to global PV installations, and 2021 closed with a record number of new countries installing significant numbers of PV. The upward trend in module prices observed at the global level at the end of 2021, related to stress on several raw materials markets, has not affected the competitiveness and development of the market. PV's role in the global transition to low-carbon energy is confirmed. 1200 TWh are produced annually by PV plants, the equivalent of the combined annual consumption of Germany, France, Spain, and Belgium. The PV capacity globally avoided no less than one billion tons of CO2, equating roughly to 3% of annual global emissions, which reached 33 Gt in 2021. PV is thus already a key decarbonization power source.

The rapid decline in PV prices over the past years, despite the conjectural recent price increase, has enabled PV systems to achieve competitive prices in several countries. The possibility of developing photovoltaic systems with limited or no financial incentives is now an observable reality. Long-term private contracts (PPA) and the sale of electricity on wholesale markets have been observed in an increasing number of countries in 2021. This growing competitiveness has also boosted the share of PV installations operating under self-consumption without any financial support mechanism. If electricity prices should remain at the high level experienced in 2022 in several places around the world in 2022, especially in Europe, the question of competitiveness would change completely: without any support scheme limitations, the potential of the PV market seems virtually unlimited.

With this broader integration, the question of access, management, and financing of the grid will become a key challenge. The electrification of the transport sector, as well as storage capacities and the production of green hydrogen, will increase the demand for low-carbon electricity. The competitiveness also paves the way for further integration in buildings, vehicles, infrastructure, and cross-cutting applications with nearly every energy-consuming sector. One of the most promising hybrid segments is called AgriPV, which combines agriculture with energy production. While still a niche market at this point, AgriPV shows significant development potential.

The social acceptance of the energy transition is a major issue and is becoming a key subject for the development of PV. It is multifaceted: economic, social, societal, and environmental, but also aesthetic. PV is a major contributor on the road to sustainability: the nature of the energy transformation, and the acceptance of change are essential elements in the success of this revolution: dealing with the number of jobs concerned, the impact on the environment and the social aspects linked to the development of PV has become unavoidable. Ensuring a local development of the PV industry and improving the use of resources is part of the response to the need for PV to be more virtuous than the energy sources that it replaces.

In 2022, photovoltaic technology has become increasingly a source of affordable, local, and low-carbon energy. In the context of geopolitical tensions and resource scarcity, PV could become a stabilization element, promoting peace through reduced tensions in energy markets while accelerating the development of the world.

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 2021

$190 BILLION USD

TOP 5 PV MARKETS IN 2021

CHINA	54.9 GW
EU	28.7 GW
USA	26.9 GW
INDIA	13.4 GW
JAPAN	6.6 GW

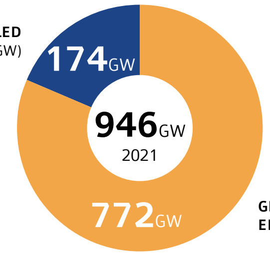
PV CONTRIBUTION TO ELECTRICITY DEMAND

5%

Share of PV in the global electricity demand in 2021

GLOBAL PV CAPACITY END OF 2021

ANNUAL INSTALLED CAPACITY IN 2021 (GW)



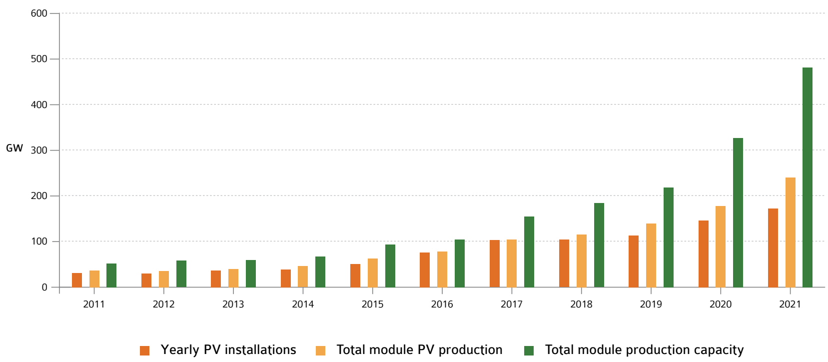
GLOBAL PV CAPACITY END OF 2020 (GW)

CLIMATE CHANGE IMPACTS

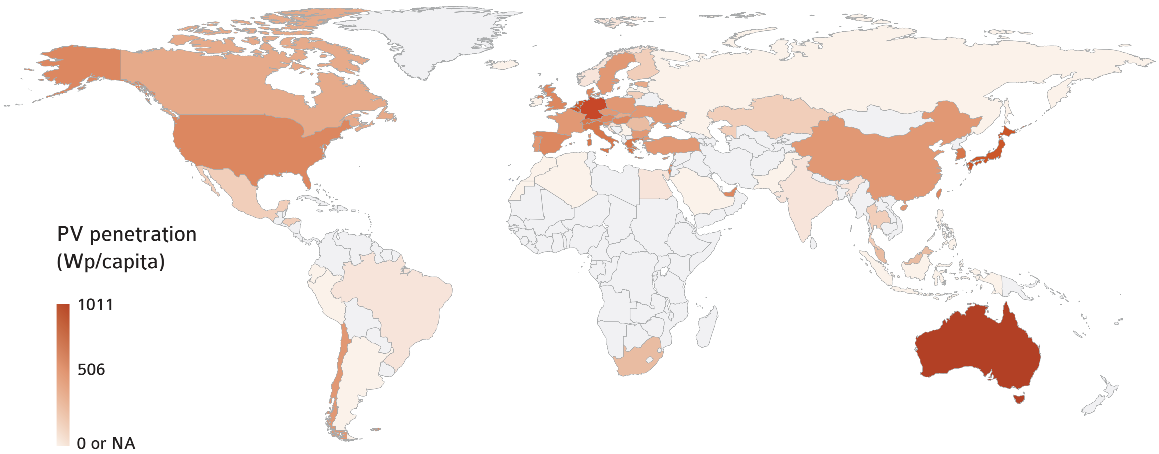
1060

million tons of CO_2 **saved** in 2021

YEARLY PV INSTALLATION, MODULE PV PRODUCTION AND MODULE PRODUCTION CAPACITY 2011-2021 (GW)



PV PENETRATION PER CAPITA IN 2021



42 COUNTRIES REACHED AT LEAST **1 GWp** IN 2021

PV POWER PER CAPITA

1. AUSTRALIA (1 011 Wp/cap)
2. THE NETHERLANDS (818 Wp/cap)
3. GERMANY (718 Wp/cap)
4. JAPAN (622 Wp/cap)
5. BELGIUM (620 Wp/cap)

18 COUNTRIES INSTALLED AT LEAST **1 GWp** IN 2021

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 it is commonly considered by industrial actors as an easy way to improve cell and modules wattage. Nowadays, wafer sizes range from 156,75 x 156,75 square mm (named M2) up to 210 x 210 square mm (named M12). To this date, there is no standard in the wafer size. Nevertheless, M10 wafers (182 x 182 square mm) and M12 have gained a lot of traction in the last year. In general, cells can be classified as either wafer-based crystalline silicon c-Si (mono- and multi-crystalline), compound semiconductor (thin-film), or organic.

Currently, c-Si technologies account for more than 95% of the overall cell production. Monocrystalline PV cells, formed with wafers manufactured using a single crystal growth method, feature commercial efficiencies between 20% and 25% (singlejunction). They have gained the biggest market share in recent years, over 85% of the c-Si share. Multicrystalline silicon (mc-Si) cells, also called polycrystalline, are formed with multicrystalline wafers, manufactured from a cast solidification process. They are still in production due to their lower production prices. Nevertheless, they are less efficient, with an average conversion efficiency of around 18%-21% in mass production (single-junction).

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 concentrated PV (CPV) systems with tracking systems or for 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.

PV TECHNOLOGY / CONTINUED

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.

Organic thin-film PV (OPV) cells use dye or organic semiconductors as the light-harvesting active layer. This technology has created 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 researched as well, with either a crystalline silicon base or a thin film base and could hit the market sooner than pure perovskites products. In 2021, perovskite solar cell achieved 28,0% efficiencies in silicon-based tandem and 23,26% efficiencies in CIGS-based tandems.

Photovoltaic modules are typically rated from 290 W to 600 W, depending on the technology and the size. 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. Their efficiency ranges between 9% (OPV), 10% (a-Si), 17% (CIGS and CIS), 19% (CdTe), 25% GaAs (non-concentrated) and above 40% for some CPV modules.

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 has 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 PV utilization 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 imposes to replace conventional building materials by some which include PV cells. 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 usually devoted to conventional building envelope solutions.

Bifacial PV modules collect light on both sides of the panel. Depending on the reflection of the ground underneath the modules (albedo), the energy production increase is estimated to 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. Indeed, recent competitive projects in desert areas boosted the market confidence in bifacial PV performance and production lines are increasingly moving towards bifacial modules. The additional factors affecting bifacial performance into their models are also better understood and integrated in the downstream industry. Bifacial PV panels have gained traction again in 2021 and are expected to take growing market shares in the coming years for utility-scale applications.

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.

Agricultural PV combine crops and energy production on the same site. 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 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 the central heating system. It also allows to reduce the operating temperature of the modules, which benefits the global performances of the system.

VIPV or vehicle integrated PV. The integration of solar cells into the shell of the vehicles allow for emissions reductions in the mobility sector. The solar cell technological developments allow to meet both aesthetic expectations for car design and technical requirements such as lightweight and resistance to load. VAPV relates to the use of PV modules on vehicles without integration.

Various Solar Home Sytems (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 solar pico PV systems have entered the market and enable starting with a small kit and adding extra loads later. They are mainly used for off-grid basic electrification, mainly 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.

Grid-connected distributed PV systems are installed to provide power to a grid-connected customer or directly to the electricity network, more specifically the distribution 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 centralized PV systems perform the functions of centralized 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 functioning independently of any nearby development.

Hybrid systems combine the advantages of PV and diesel generator in mini grids. They allow mitigating 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. 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.

PV APPLICATIONS AND MARKET SEGMENTS / CONTINUED

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.

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 are reporting 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 an increasing share of the global installed PV capacity is attaining a certain lifetime - the very first waves of installations dating back to the nineties - performance losses and decommissioning must be considered to calculate the PV capacity and PV production.

For this report, the PV penetration was estimated with the most recent global data about the PV installed capacity, the average theoretical PV production and the electricity demand based. In general, PV penetration is amongst one of the best indicators to reflect the market dynamics in a specific country or region. If a global PV penetration level does not reflect the regional disparities, it gives an indication about the ability of the technology to keep up with the global demand growth. Hence, regarding climate goals for instance, the PV penetration is a better indicator than the absolute market growth.

Photo by Denis Schroeder, NREL 55200

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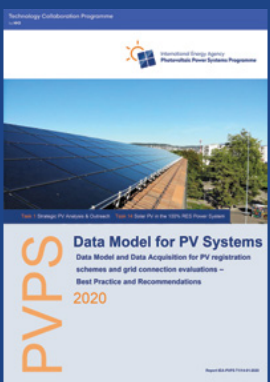
PV MARKET DEVELOPMENT TRENDS

Since the early beginnings of the PV market development, over 945,4 GW of PV plants have been installed globally, of which around 70% 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 2021 closed with a record number of new countries installing significant PV numbers.

A large majority of PV installations are grid-connected and include an inverter which converts the variable direct current (DC) output of solar modules into alternating current (AC) to be injected 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 in DC to maintain coherency. When official reporting is in AC, announced capacities are mentioned as MWac or MWdc in this report. By default, MW implies capacities mentioned in DC.

For more information on registering PV installations, download the IEA PVPS report on registering PV installations published recently.

Download the "data Model for PV System" reports:



THE GLOBAL PV INSTALLED CAPACITY

Global PV installed capacity (GW)

+22% YoY growth

At the end of 2021, the global PV installed capacity represented 945,4 GW of cumulative PV installations.

Presently it appears that 173,5 GW represented the minimum capacity installed during 2021 with a reasonably firm level of certainty. This level is the highest ever recorded for PV installations, despite the pandemic related perturbations which have delayed market development in several countries. The real impact of the pandemic is difficult to estimate, since the delays observed in the first part of the year were sometimes compensated in the second part. However, it seems reasonable that many projects might have been delayed. In addition, prices increased and logistic issues possibly reduced the installations in the last part of the year 2021. Hence the market results could have probably been even higher, reflecting the sector mood.

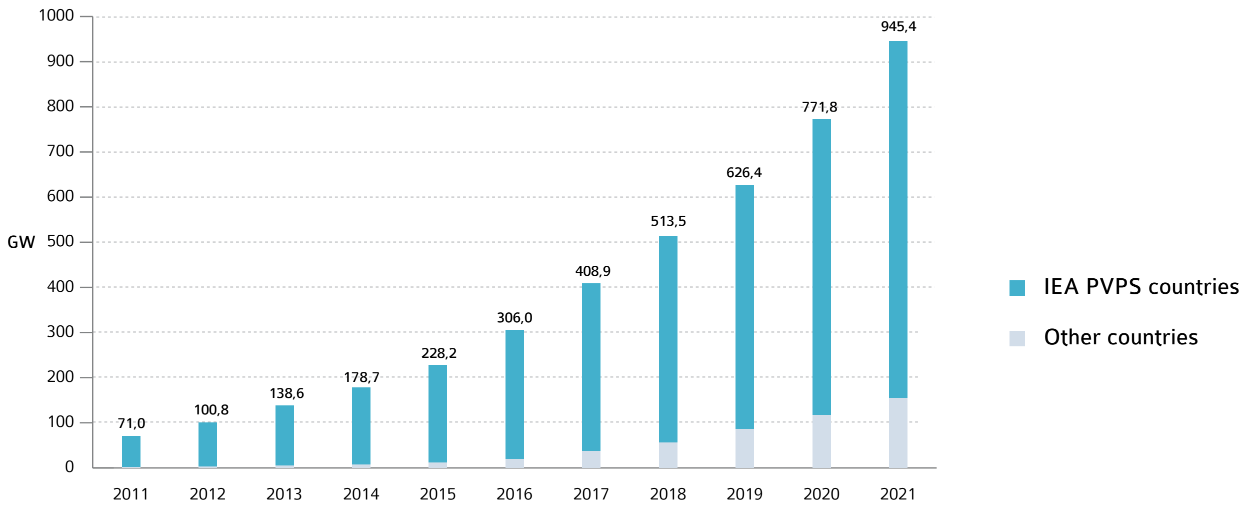
The group of IEA PVPS countries represented 753 GW of the global installed capacity. The IEA PVPS participating countries in 2021 are Australia, Austria, Belgium, Canada, Chile, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia,

THE GLOBAL PV INSTALLED CAPACITY / CONTINUED

Mexico, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America.

The other key markets that have been considered and which are not part of the IEA PVPS Programme, represented a total cumulative capacity of 154,3 GW at the end of 2021. Amongst them, India covered around one third of that capacity with 61 GW. Vietnam reached 18,4 GW after three years of important PV development (in particular over 11 GW installed in 2020). 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 14,6 GW, Poland with 7,7 GW, Ukraine with over 6 GW, Greece with 5 GW, the Czech Republic with 2,0 GW installed, Romania with 1,6 GW, and Bulgaria almost 1,3 GW. The other major countries that accounted for the highest cumulative installations at the end of 2021 and that are not part of the IEA PVPS programme are: Brazil with 13,7 GW, and Taiwan with 7,7 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 Africa (Egypt, South Africa) and in the Middle East (UAE) which led to GW-scale installation levels: 4,6 GW in South Africa, 3,5 GW in the UAE and 3,4 in Egypt for instance.

FIGURE 2.1: EVOLUTION OF CUMULATIVE PV INSTALLATIONS



SOURCE IEA PVPS & OTHERS

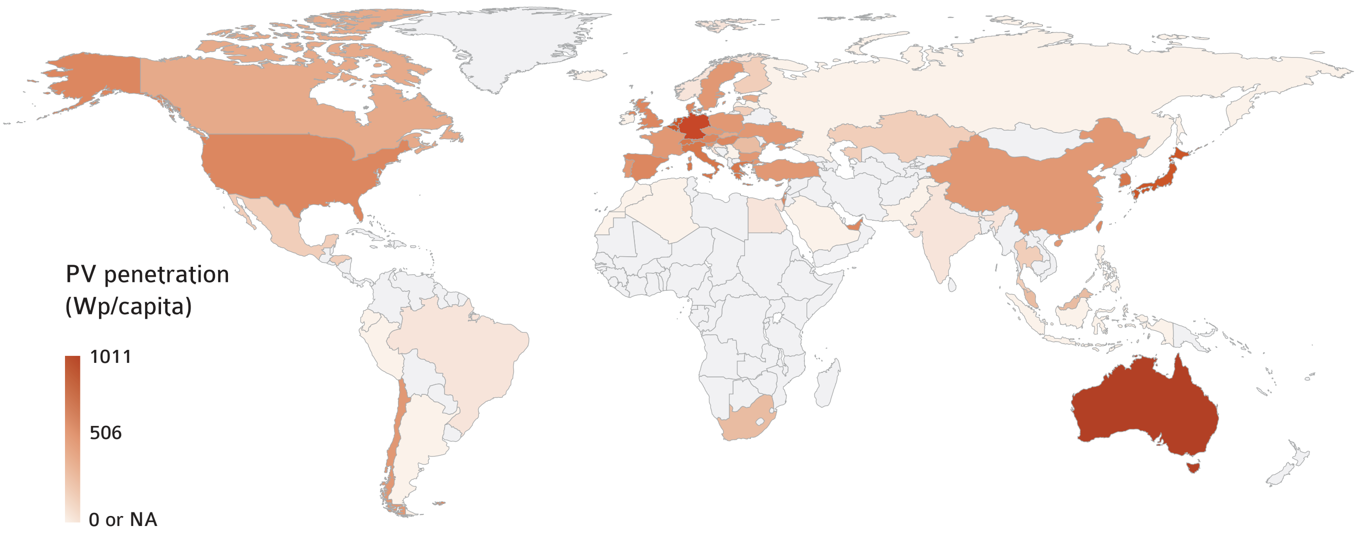
PV PENETRATION PER CAPITA

In just a few years, Australia has reached the highest installed PV capacity per inhabitant with 1 011 W/cap in IEA-PVPS and surveyed countries. The Netherlands is second with 818 W/cap. Germany comes next with 718 W/cap followed by Japan with 622 W/cap and Belgium with 620 W/cap. Switzerland and Korea nearly tied at the 6th place with respectively 422 W/cap and 416 W/cap. Denmark (399 W/cap) and Spain (396 W/cap) come next. Italy and the USA are closing the top 10 (among IEA PVPS countries) with 374 and 371 W/cap.

As a comparison, 500 W represents the power of a large PV module, one can say that in some countries one module per person have been installed.

> Australia has reached the highest installed PV capacity per inhabitant with **1 011 W/cap.**

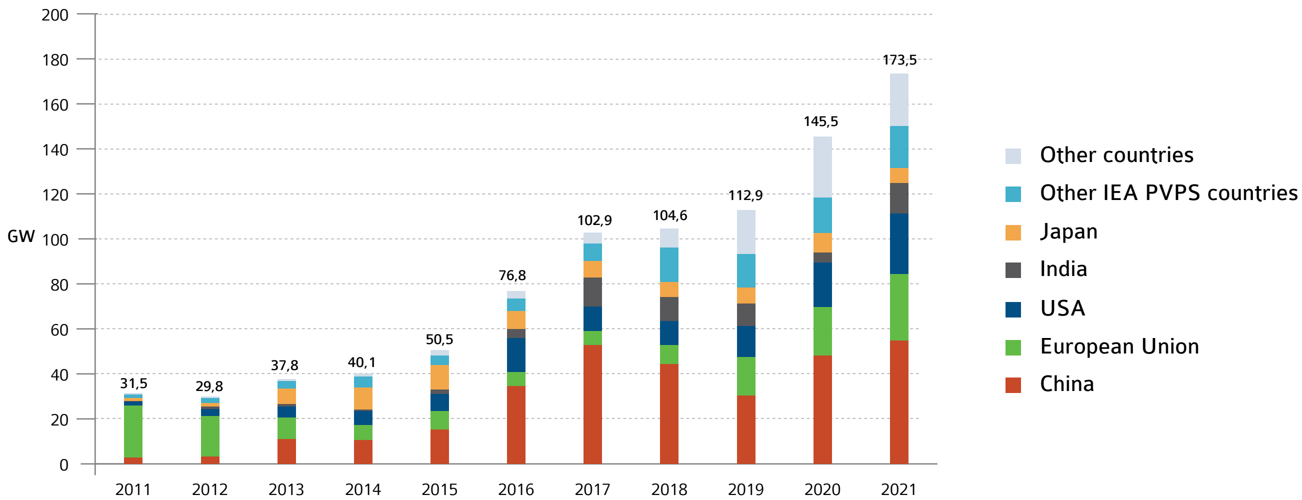
FIGURE 2.2: PV PENETRATION PER CAPITA IN 2021



SOURCE IEA PVPS & OTHERS

EVOLUTION OF PV ANNUAL INSTALLATIONS

FIGURE 2.3: EVOLUTION OF ANNUAL PV INSTALLATIONS



SOURCE IEA PVPS & OTHERS

THE GLOBAL PV INSTALLED CAPACITY / CONTINUED

The IEA PVPS countries installed at least 129 GW in 2021. While they are more difficult to track with a high level of certainty, installations in non-IEA PVPS countries contributed an estimated amount of 44 GW. The noteworthy trend of 2021 is the important year on year growth for the second year in a row, of the global PV market despite the supply chain turmoil which could have paused or delayed market development in some countries. As in 2020, the rise of emerging markets in addition to the growth of key markets contributed to this market growth in 2021.

For the ninth year in a row, China was in the first place and installed almost 55 GW in 2021, according to China's National Energy Administration; an installation level that surpassed the level reached in the country in 2017 (52,8 GW). The total installed capacity in China reached 308,5 GW, and by that the country kept its market leader position in terms of total installed capacity. The Chinese market represented 31% of the global installation in 2021.

Annual PV installations (GW)

+19% YoY growth

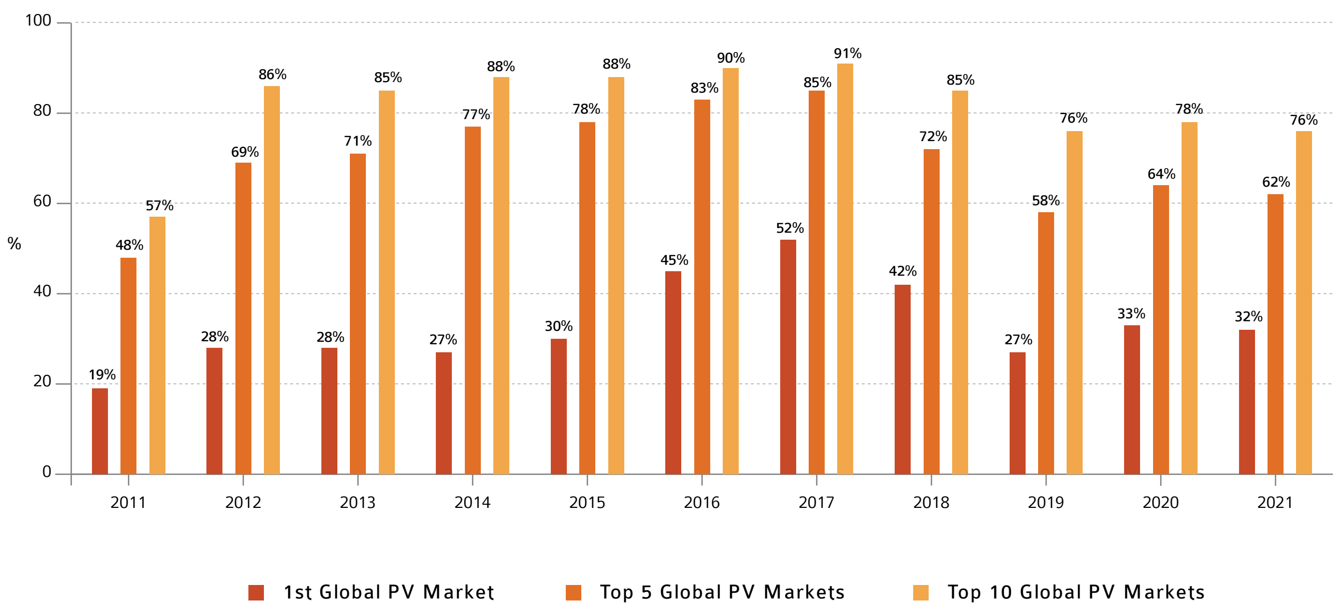
Second was the European Union, which experienced growth for the third year in a row with 28,7 GW, which exceeds the 23,2 GW recorded in 2011. Germany (5,8 GW) and Spain (4,9 GW) were the key markets this year followed by Poland (3,7 GW), the Netherlands (3,6 GW) and France (3,4 GW) and several others.

Third was the United States with 26,9 GW installed, marking a significant growth again compared to the previous year making 2021 the largest single year increase in installations in the U.S. Both the utility sector installations and the residential market increased over 2020 installation levels. At the end of 2021, the U.S. reached 123 GW of cumulative installed capacity.

India was in fourth place with 13,7 GW installed, bringing back the annual market to levels close to those observed in 2017, 2018 and 2019. The official number has been recalculated based on official AC data using IEA PVPS assumptions on AC-DC ratio.

The market in Japan contracted slightly with 6,6 GW in 2021, its lowest level since 2012.

FIGURE 2.4: EVOLUTION OF MARKET SHARE OF TOP COUNTRIES



SOURCE IEA PVPS & OTHERS

Together, these five leading individual or block of countries represented around 75% of all installations recorded in 2021, the same level as in 2020. In terms of cumulative installed capacity, these countries represent 76% of the global capacity. This shows that the global PV market concentration is again increasing, with new markets contributing proportionally less to global installation numbers than established ones.

Behind the top 5, Brazil installed 5,7 GW leading to a cumulative market of 13,7 GW in 2021. After years of limited PV market development, Brazil appears now as one of the key global players, demonstrating its much higher potential than the levels reached until now.

Australia installed 4,9 GW in 2021, a stable level since 2018 and a tremendous level given the country's population. For several years the country has been experiencing a boom in utility-scale applications together with a robust demand for distributed PV systems. The total installed PV capacity reached 26 GW at the end of 2021.

Korea installed 4,2 GW in 2021 with an important share of utility-scale plants, a slight decrease compared to 2020 when the highest level of installations ever in the country was recorded. Korea is one key industrial actor in the PV sector, with several key players such as Hanwha and OCI.

Chile's position in the top 10 countries for PV installations comes from 2,7 GW installed in 2021, marking a tremendous boom in PV market development in the country.

In the tenth position comes Vietnam where PV installations significantly decreased after the massive growth observed in 2020. In total around 2 GW were installed.

Together, these 10 markets cover around 76% of the 2021 annual world market, a sign that the growth of the global PV market has been driven by a limited number of countries again, and this even if the remaining markets are starting to contribute more significantly. 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. As shown in Figure 2.4, the market concentration steadily decreased in 2019 before growing again in 2020 and stabilising in 2021, mostly due to the growth of the Chinese PV market. As new markets are starting to emerge, the versatility 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 2021, China's installations maximized the global growth.

The level of installations required to be included in the top 10 (country wise) has increased steadily since 2014: from 0,78 GW to 1,6 GW in 2018, and around 3,5 GW in 2020 and 2021. This reflects the global growth trend of the solar PV market, but also its variations from one year to another.

Considering the **European Union** (a member of the IEA PVPS) as one entity rather than a collection of markets is an editorial choice of the writers. Considering the European PV Markets separately, **Germany** would rank fifth, **Spain** eighth and **Poland** tenth. This doesn't change the general conclusions of this chapter; the ten first countries would cover 76% of the global PV market.

TABLE 2.1: EVOLUTION OF TOP 10 MARKETS

RANKING	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1	ITALY	GERMANY	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA
2	GERMANY	ITALY	JAPAN	JAPAN	JAPAN	USA	INDIA	INDIA	USA	USA	USA
3	CHINA	CHINA	USA	USA	USA	JAPAN	USA	USA	INDIA	VIETNAM	INDIA
4	USA	USA	GERMANY	UK	UK	INDIA	JAPAN	JAPAN	JAPAN	JAPAN	JAPAN
5	FRANCE	JAPAN	ITALY	GERMANY	INDIA	UK	TURKEY	AUSTRALIA	VIETNAM	GERMANY	GERMANY
6	JAPAN	FRANCE	UK	SOUTH AFRICA	GERMANY	GERMANY	GERMANY	TURKEY	AUSTRALIA	AUSTRALIA	BRAZIL
7	BELGIUM	AUSTRALIA	ROMANIA	FRANCE	KOREA	THAILAND	KOREA	GERMANY	SPAIN	KOREA	AUSTRALIA
8	UK	INDIA	INDIA	KOREA	AUSTRALIA	KOREA	AUSTRALIA	MEXICO	GERMANY	INDIA	SPAIN
9	AUSTRALIA	GREECE	GREECE	AUSTRALIA	FRANCE	AUSTRALIA	BRAZIL	KOREA	UKRAINE	SPAIN	KOREA
10	GREECE	BULGARIA	AUSTRALIA	INDIA	CANADA	TURKEY	UK	NETHERLANDS	KOREA	NETHERLANDS	POLAND
RANKING EU	1	1	2	3	3	4	5	4	2	2	2
MARKET LEVEL TO ACCESS THE TOP 10											
	426 MW	843 MW	792 MW	779 MW	675 MW	818 MW	944 MW	1 621 MW	3 130 MW	3 492 MW	3 710 MW

THE GLOBAL PV INSTALLED CAPACITY / CONTINUED

As detailed above, the IEA PVPS choice consists in reporting DC capacities. An estimate of AC capacities would put the new installed capacities number around 129 GW in 2021. 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 the last years or were found in the top 10 countries, didn't succeed in maintaining a sufficiently high level of installations to stay in the rankings: Mexico, Turkey, France and many other countries. The versatility of the markets is a feature of the PV industry that, from its inception, had to deal with changes in policies and therefore in market development. This is levelizing progressively with PV reaching competitiveness faster than many expected.

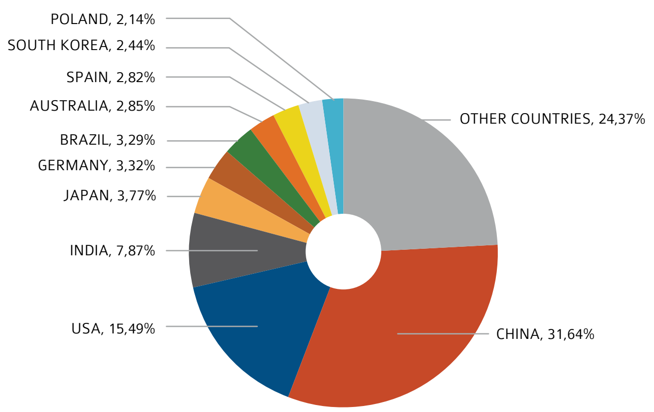
After having reached GW-scale installations in 2019 and 2020, PV deployment declined in Egypt in 2021, with 300 MW installed. In the UAE, almost 700 MW came online in 2021 through large-scale tenders, amongst the most competitive globally. Self-consumption policies didn't contribute much but could represent a complementary driver in the near future. Mexico's annual installations maintained their 2020 level with 1,6 GW in 2021, in a complex policy environment, which might put the brakes on its market in the coming years.

Other countries reached significant installation levels in 2021: Around 3,7 GW of PV installations were added in Poland in 2021, mostly as small distributed installations. 3,6 GW were installed in the Netherlands, 3,4 GW in France marking a significant growth compared to previous year and also 1,9 GW in Taiwan, 1,5 GW in Turkey and 1,2 GW in Greece.

Other countries that installed significant amounts of PV but below the GW mark, were Israel (940 MW), Italy (944 MW), Belgium (850 MW), Hungary (800 MW), Austria (740 MW), the UK (730 MW) and Denmark (720 MW). The market uptake in the European Union makes it the second largest market globally.

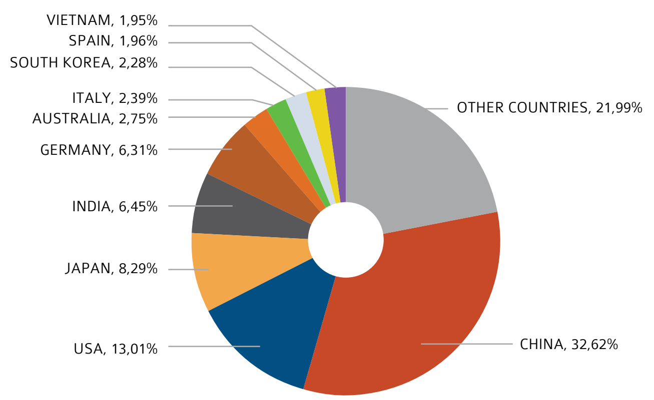
The total installed capacity in most surveyed countries takes decommissioning of PV plants into account. While such numbers remain relatively limited for the time being, they start to impact numbers at a very low level, which can lead to discrepancies in national statistics of several IEA PVPS countries. Off-grid numbers are difficult to track and most numbers are estimates. Changes (including repowering) and decommissioning are higher for these applications than in other segments and can lead to numerical glitches. In this report, global annual installations and the cumulative capacity are computed based on a variety of sources and could, despites all efforts, differ from other publications. The development in many non-IEA countries is an estimate, due to the lack of official statistics in numerous countries.

FIGURE 2.5: GLOBAL PV MARKET IN 2021



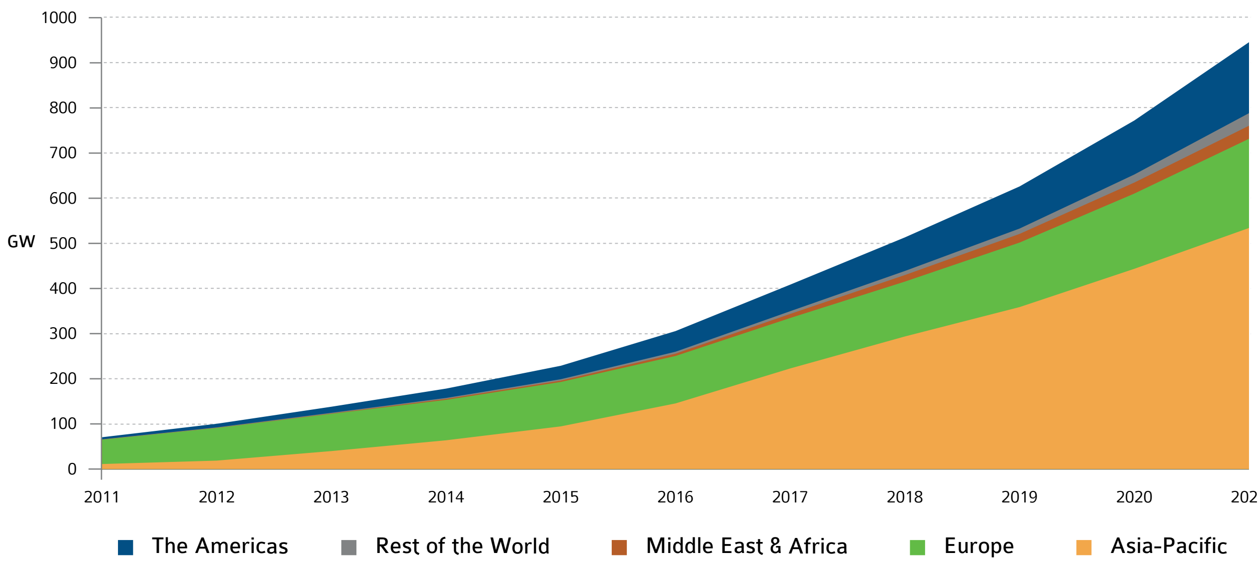
SOURCE IEA PVPS, RTS CORPORATION

FIGURE 2.6: CUMULATIVE PV CAPACITY END 2021



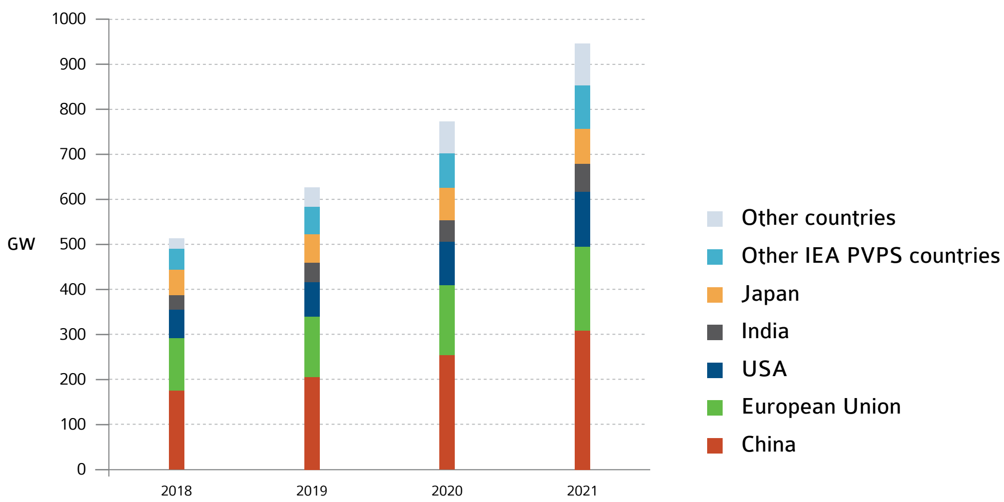
SOURCE IEA PVPS, RTS CORPORATION

FIGURE 2.7: EVOLUTION OF REGIONAL PV INSTALLATIONS



SOURCE IEA PVPS & OTHERS

FIGURE 2.8: 2018-2021 GROWTH PER REGION



SOURCE IEA PVPS & OTHERS

PV MARKET SEGMENTS

Solar PV experienced another growth year mainly 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. Although the role of distributed generation should not be underestimated, utility-scale PV is likely to keep dominating electricity generation in many countries. The main reason is that economies of scale outweigh the savings in transmission costs and the self-consumption possibilities brought by embedded installations.

Ground mounted utility-scale PV installations increased in 2021 with more than 95 GW, compared to 86 GW in 2020 and 71 GW in 2019. However, the share of utility-scale still represented around 55% of cumulative installed capacity because distributed PV also grew significantly, up to 78 GW in 2021 compared to 59 GW in 2020. Off-grid and edge-of-the-grid applications are increasingly integrated in these two large categories.

UTILITY-SCALE PV: THE PV MARKET DRIVING FORCE

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

Due to the simplicity of setting up policies to develop them, with or without tenders, utility-scale applications are thriving in new PV markets. More countries are proposing tendering processes to select the most competitive projects. Merchant PV, where PV electricity is directly sold to electricity markets or (C-)PPAs, where it is directly sold to (corporate) consumers is experiencing growth in numerous countries, but this market driver remains limited so far.

One of the key trends of 2021 is the wider development of utility-scale plants without financial incentives (on wholesale electricity markets or from private customers). Such development is mostly independent from financial incentives and therefore policy decisions, which makes its potential virtually unlimited. Limitations are already seen due to grid congestion in some places: this has modified the tendering approaches which might lead to bidding at the lowest possible cost to secure a grid connection. This has been seen in Portugal for instance.

New utility-scale PV plants are increasingly using trackers to maximise production and in parallel, the use of bifacial PV modules increases relatively fast as well. The addition of storage systems also becomes a trend in some countries, either pushed by specific rules in tenders or by the willingness to better serve the wholesale and grid services markets. In 2021, utility-scale plants amounted to 95 GW globally and the total installed capacity for all of these applications amounted to 534 GW; or 56% of the cumulative installed capacity.

TABLE 2.2: TOP 10 COUNTRIES FOR CENTRALIZED PV INSTALLED IN 2021

COUNTRY	GW
CHINA	25,60
USA	20,26
INDIA	11,62
SOUTH KOREA	4,00
SPAIN	3,50
JAPAN	2,99
NETHERLANDS	2,35
FRANCE	2,22
GERMANY	2,01
AUSTRALIA	1,71

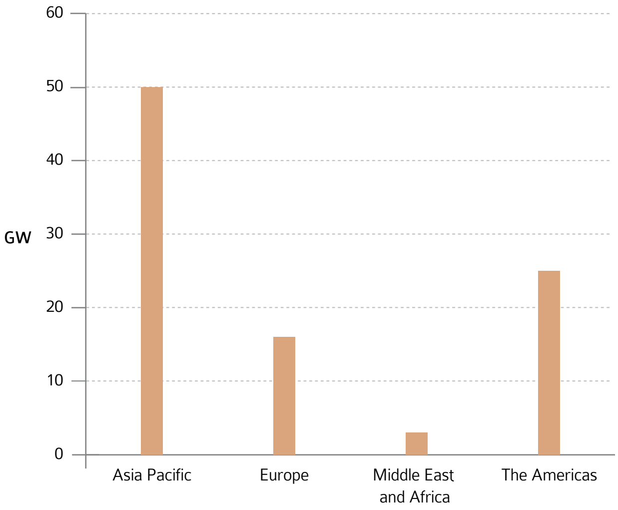
SOURCE IEA PVPS

TABLE 2.3: TOP 10 COUNTRIES FOR CUMULATIVE CENTRALIZED PV INSTALLED CAPACITY IN 2021

COUNTRY	GW
CHINA	199,94
USA	80,33
INDIA	52,90
JAPAN	30,12
SOUTH KOREA	18,91
SPAIN	15,23
GERMANY	11,10
AUSTRALIA	9,00
NETHERLANDS	8,49
UK	8,35

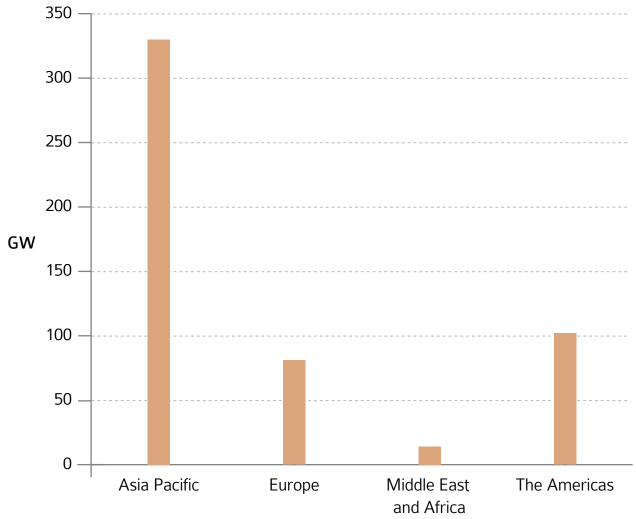
SOURCE IEA PVPS

FIGURE 2.9: CENTRALIZED PV INSTALLED CAPACITY PER REGION 2021



SOURCE IEA PVPS & OTHERS

FIGURE 2.10: CENTRALIZED PV CUMULATIVE INSTALLED CAPACITY PER REGION 2021



SOURCE IEA PVPS & OTHERS

PROSUMERS, EMPOWERING CONSUMERS

Prosumers are consumers producing part of their own electricity consumption.

Historically driven by simple financial incentives such as net-metering, prosumers segments increasingly develop thanks to various schemes based on the concept of self-consumption. Indeed, the new generation of solar schemes is often making the distinction between the electricity consumed and the electricity injected into the grid, thereby incentivizing self-consumption.

An important factor in the success of self-consumption schemes is the retail electricity price which 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, also in market segments involving self-consumption. Conversely, the PV market tends to grow quickly when electricity prices increase. Overall, there is a trend toward self-consumption of PV electricity in most of countries, often with adequate regulations offering a value for the excess electricity. This can be done with a FiT, a feed-in-premium added to the spot market price or more complex net-billing. Unfortunately, the move towards pure self-consumption schemes can create temporary market slowdowns, especially if the transition is abrupt. However, if the market conditions are favourable and the market regains confidence, self-consumption can become a market driver.

The distributed market has been oscillating around 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 to more than 36 GW globally in 2017 to 78 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 which requires to use the public grid (distributed or virtual or delocalized self-consumption), to share the self-generated electricity, thereby unlocking access to self-consumption for a wide range of consumers. Such regulation, if well implemented, will allow 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 adequacy between 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 the grid costs.

PV MARKET SEGMENTS / CONTINUED

TABLE 2.4: TOP 10 COUNTRIES FOR DISTRIBUTED PV INSTALLED IN 2021

COUNTRY	GW
CHINA	29,28
USA	6,62
BRAZIL	4,16
GERMANY	3,75
JAPAN	3,55
AUSTRALIA	3,20
POLAND	2,90
INDIA	2,04
TAIWAN	1,59
SPAIN	1,40

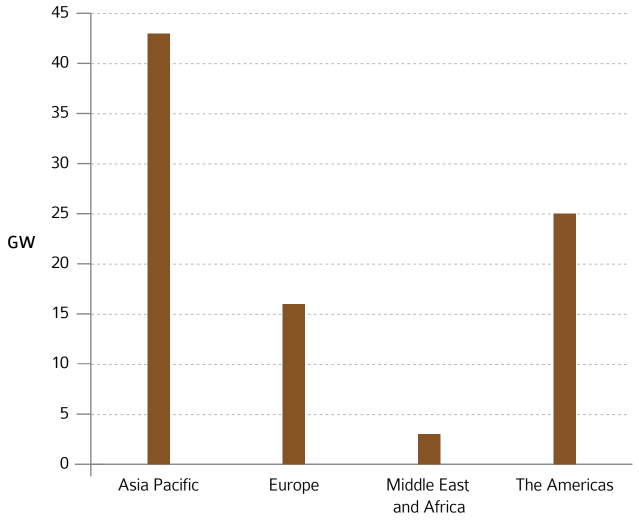
SOURCE IEA PVPS

TABLE 2.5: TOP 10 COUNTRIES FOR CUMULATIVE DISTRIBUTED PV INSTALLED CAPACITY IN 2021

COUNTRY	GW
CHINA	108,22
GERMANY	48,56
JAPAN	48,11
USA	42,68
AUSTRALIA	16,68
ITALY	14,55
VIETNAM	10,46
TURKEY	9,73
BRAZIL	9,08
FRANCE	8,70

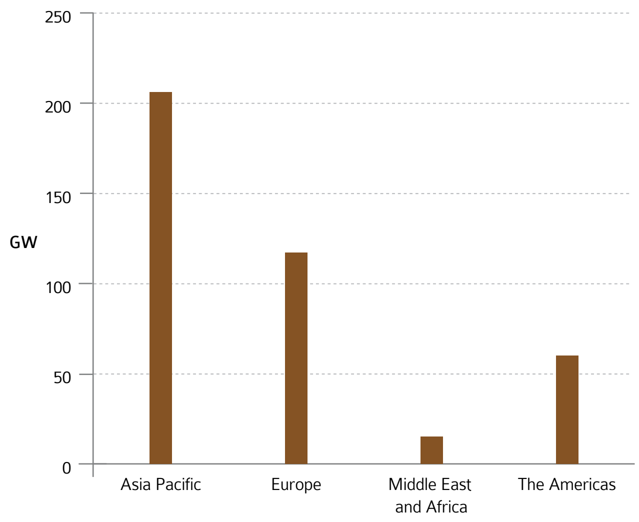
SOURCE IEA PVPS

FIGURE 2.11: DISTRIBUTED PV INSTALLED CAPACITY PER REGION 2021



SOURCE IEA PVPS & OTHERS

FIGURE 2.12: DISTRIBUTED PV CUMULATIVE INSTALLED CAPACITY PER REGION 2021

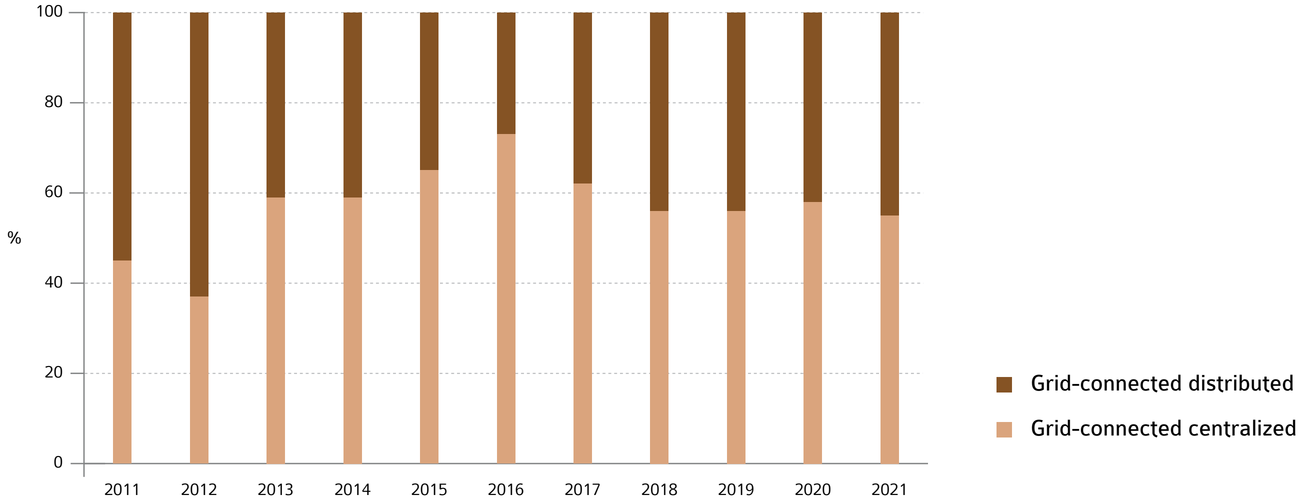


SOURCE IEA PVPS & OTHERS

EMERGING PV MARKET SEGMENTS

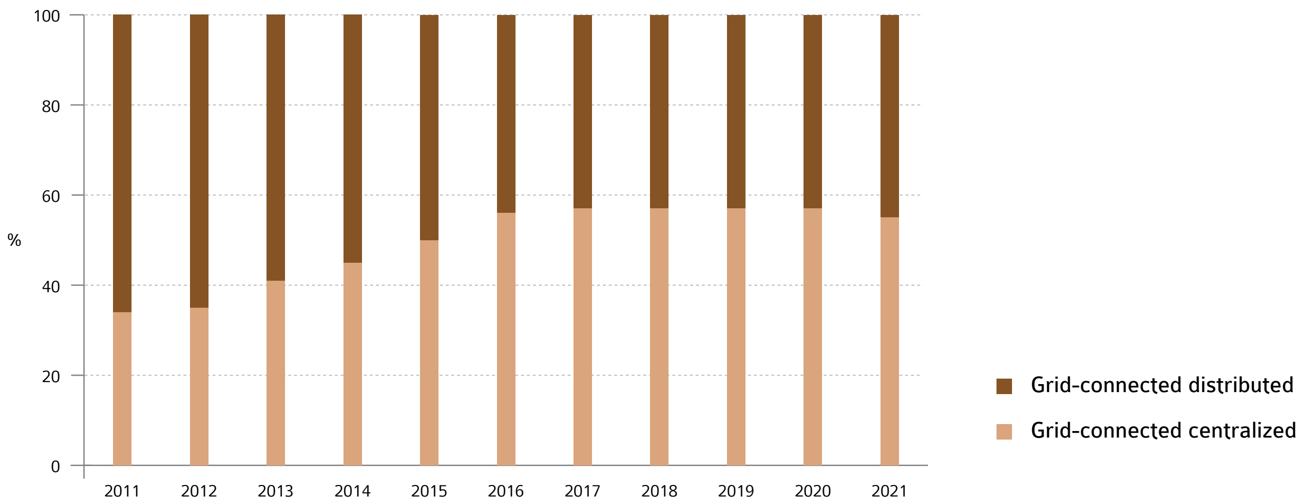
Globally, centralized PV continued to represent 56% of the market in 2021, mainly driven by China, the USA, and emerging PV markets. In the same trend as in previous years, 2021 saw again some new records in terms of PV electricity prices through extremely competitive tenders. Although renewed competitive tenders contributed to the utility-scale market, distributed PV also increased significantly in 2021, with around 78 GW installed; with 29,3 GW from China alone. Remarkably, the distributed segment took off in the Middle East due to adequate policies in Israel and Jordan.

FIGURE 2.13: ANNUAL SHARE OF CENTRALIZED AND DISTRIBUTED GRID-CONNECTED INSTALLATIONS 2011 – 2021



SOURCE IEA PVPS & OTHERS

FIGURE 2.14: CUMULATIVE SHARE OF GRID CONNECTED PV INSTALLATIONS 2011 – 2021



SOURCE IEA PVPS & OTHERS

EMERGING PV MARKET SEGMENTS / CONTINUED

With the exception of the European market which incentivized residential segments from the start, initially most of the major PV developments in emerging PV markets are coming from utility-scale PV. This evolution 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.

FLOATING PV: A GROWING MARKET SEGMENT

The installed capacity of Floating PV (FPV) systems worldwide has surpassed 3 GWp in 2021, according to data from the Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore (NUS). SERIS maintains a global database of close to 700 projects in operation and more than 300 projects under planning, development, or construction.

Apart from some installations in Europe, especially in the Netherlands, France, and the UK, Floating Solar is so far mostly located in Asia with more than 85% deployed in East and South-East Asia. In densely populated areas the proximity of water bodies to load centers 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 high cost of land. This is also why Japan was one of the early adopters of Floating PV and still has the highest number of FPV projects (~200). Floating PV is even possible in city states such as Singapore, which inaugurated a 60 MWp FPV plant in June 2021 and has called for a study for another 140 MWp. The highest installed FPV capacity to-date is deployed in China (a total of 1,3 GWp) where developers largely took advantage of water bodies that were created when former coal mines filled-up with ground water. These so-called subsidence areas are almost ideal as they are considered as unstable territories (hence not suitable for industrial or agricultural activities) and often have little bioactivities (leading to minimal environmental impacts).

Another great opportunity for Floating Solar is the combination with existing hydropower dams. This is even more so 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 cloud some of the short-term variability from solar (due to could movements) and hence use the reservoirs as a "giant battery". Many of the announced Floating Solar projects are on hydropower reservoirs, for example in Thailand (3,5 GWp), Korea (2,1 GWp) and Laos (1,2 GWp).

Another area of increasing interest are near-shore and off-shore marine floating PV projects. Such projects will see additional challenges but also almost endless opportunities. The challenges are the much more demanding environments, where tidal currents, richer marine life, wind, waves and the presence of salt water all need to be considered. But the opportunities in near-shore areas alone are enormous: significant unused space can be activated for energy harvesting close to load centers in coastal settlements and harbours. Going further off-shore aggravates the challenges and cost but still has possible applications, especially for powering oil & gas platforms or for utilising the vast ocean spaces between the towers in off-shore wind farms. In those cases, the FPV project would take advantage of the existing transmission infrastructure and also of the fact that solar and wind generation are often complementary in their resource availability. The first such testbeds are being set up in the Netherlands and Belgium.

In terms of floating structures, the vast majority of the FPV installations in operation use HDPE plastic floats, for which Ciel & Terre and Sungrow together have more than 50% market share. There is an increasing number of players, however, which follow 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.

AGRI-PV: DUAL USE IS EXPECTED TO EMERGE FAST

The development of PV on agricultural land had existed since the beginning of utility-scale PV but, in some cases, crops have been replaced by photovoltaics and thus the use land was mostly shifted from agriculture towards electricity production. Agri-PV proposes a different perspective with the possibility to use land for both purpose: food and energy production. With higher PV penetration rates, competition for land can limit PV development in a certain number of countries. Dual use of land is an option deeply investigated around the world to address this topic.

PV potential on agricultural land and how it can contribute to achieving renewable energy targets have been highlighted in some regions, and interest but also reluctance increased. On one hand the agri-PV market potential is unsurpassed. 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, while 6,5 GW have been installed in 2021 for all the segments reaching 78,2 GW cumulative installed capacity. South Korea's perspective of agri-PV development is 10 GW in 2030, which is half of the cumulative installed capacity at the end of 2021 (21,5 GW). In France, between 5 and 10 GW could be installed using 0,1% of the agricultural land (agricultural land covers half of the French territory) while annual installations achieved 3,4 GW in 2021. The potential of 1% of the European Union's agricultural lands had been calculated at 410 GW while 29,3 GW were installed in the European Union installed in 2021.

Even if PV potential is huge, other strong considerations must be taken into account. Food production security and sufficiency are the first priority. The various crises in 2020 and 2021 highlighted how crucial these aspects are. The agricultural sector's economic balance, environmental evaluation, social acceptance and water management must be assessed and shape future regulations to ensure sustainable development. Following pioneer countries such as Japan, where "solar sharing" has been defined since 2003, and refers to PV installation above 2 m where 80% of agricultural yields are maintained, France, Germany and Italy have published frameworks or guidelines in 2022.

Cross-sectorial groups have been working on frameworks. Defining "agrivoltaic", or "agrovoltaic", "agri-PV" is challenging but a trend is clear: not every PV installation set up in an agricultural environment is considered an agrivoltaic installation, and most existing plants on agricultural land could hardly qualify as such. Along the publications of the different frameworks and support mechanisms, in most countries agriPV or PV in agricultural land is segmented:

- PV systems above the crops or plants. The system allows raising different kinds of crops with reduced solar insolation, allowing better development in sunny regions, and possibly new business models - such as recovery of damaged crops for instance - or growing different crops that would not have been profitable in some regions. This dual use imposes a different kind of PV systems, which can in some cases change their position, from horizontal to vertical and be designed either to maximize PV production or maximize crop production depending on the weather conditions. Tracking systems are not the only component that can help maintain or enhance agricultural production which is a prerequisite to be labelled as agri-PV. Agricultural production profitability must dominate, and energy production is an added value.
- Crops, grassland, animal husbandry between PV systems. The systems must enable the land to maintain its agricultural purpose. The space between the rows or the heights is adapted. These systems are economically performant and cost effective. Energetic production dominates but agricultural production must be maintained.

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 agri-PV typically receive higher incentives or, in some countries, are even the only type of PV plant allowed to be developed in agricultural areas.

For now, agriPV is still an emerging market. Japan has seen more than 1 800 agriPV farms realised, most of them are small systems. Between 2013 and 2018, approximately 150 MW were installed, and between 500 to 600 MW in 2021. China has also an important capacity installed but this segment doesn't appear to be monitored separately. Italy announced a major funding package support for 2 GW, including the so-called agriPV on roofs of rural areas. Specific calls for tender have been set for agri-PV in numerous countries: in France for around 300 MW, in Germany for 150 MW, in Israel for 100 MW, and in the Netherlands for 45 MW.

BIPV: WAITING FOR THE UPTAKE

The BIPV market remains a niche which 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 products. Depending on the definition considered, the BIPV market ranged from 200 MW to 400 MW per year in Europe last year and probably reached 1 GW globally. Indeed, the differences between custom-made elements and traditional glass-glass modules can be difficult to assess. In that respect, simplified BIPV, using conventional PV modules with dedicated mounting structures, experienced positive developments in numerous EU countries in 2021, and is 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.

OFF-GRID MARKET DEVELOPMENT

Numbers for off-grid applications are generally not tracked with the same level of accuracy as grid-connected applications. The off-grid and edge-of-the-grid market can hardly be compared to the grid-connected market because the rapid deployment of grid-connected PV dwarfed the off-grid market. 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.

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.

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, this trend remains unseen, and the future development of off-grid applications will most probably only be seen on remote islands.

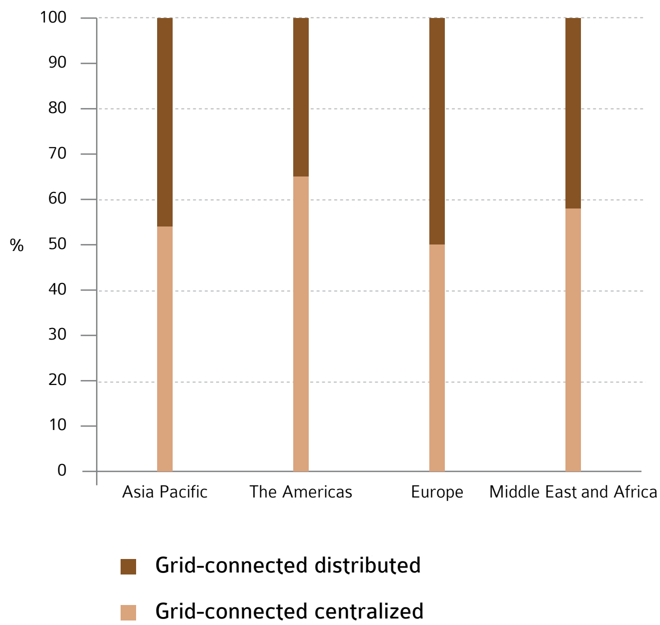
PV DEVELOPMENT PER REGION

The early PV developments 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 from around 200 MW in 2000 to around 1 GW in 2004, the market started to grow very fast, thanks to European markets in 2004. In 2008, Spain fuelled market development while Europe as a whole accounted for more than 80% of the global market: a performance repeated until 2010. From around 1 GW in 2004, the market doubled in 2007 and reached 8 GW and 17 GW in 2009 and 2010.

From 2011 onward, the share of Asia and the Americas started to grow rapidly, with Asia taking the lead. This evolution is quite visible and still true today, with the share of the Asia-Pacific region stabilizing around 54% in 2021. 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 CENTRALIZED AND DISTRIBUTED PV INSTALLATIONS BY REGION IN 2021



SOURCE IEA PVPS & OTHERS

THE AMERICAS

The Americas represented 40 GW of installations and a total cumulative capacity of 164 GW in 2021. Whilst most of these capacities are installed in the USA, several countries have started to install PV in the central and southern countries of the continent: first in Chile and Honduras and more recently in Mexico and Brazil.

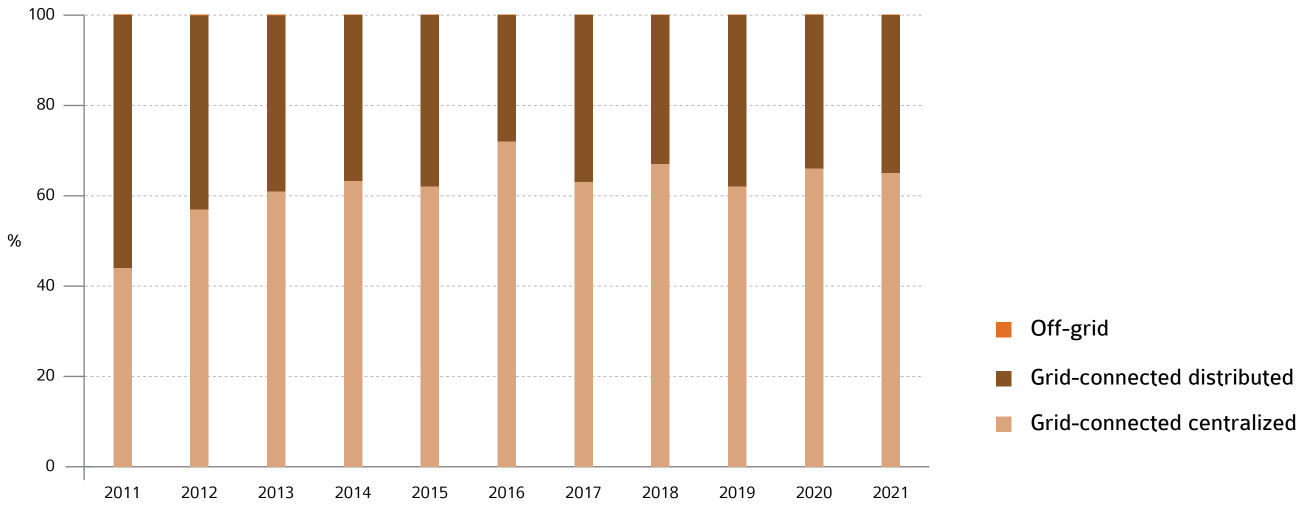
PV is developing in the Americas mostly through tenders except in the USA. Distributed applications start to develop in several countries. Next to the USA market that dominates by far, instability has characterized the development of PV in most American countries in the last years, with stop-and-go policies in Canada, Honduras or Mexico for instance. The market was dynamic in 2021 in Chile and Brazil, to mention these two, 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: it finished the year 2021 with 13,7 GW of cumulative PV installed capacity with most of the newly installed capacity coming from distributed generation. PV installations in Chile grew in 2021 reaching a cumulative installed capacity of 6,2 GW.

In other countries, such as Argentina, development is starting to take off, with around 960 MW cumulative installed capacity in the country at the end of 2021 and 200 MW installed in 2021. Other multi-MW installations have been reported in Peru in recent years, in Honduras or in Colombia.

Several other countries in Central and Latin America have put support schemes in place for PV electricity, and an increasing number of power plants are connected to the grid mainly in Dominican Republic, Ecuador and El Salvador, closely followed by Uruguay and Panama which could indicate that the time has come for PV in the Americas. In countries with a high hydroelectricity contribution to the electricity mix, such as Venezuela, PV could become an alternative to the variable production due to changes in rain patterns.

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



SOURCE IEA PVPS & OTHERS

ASIA-PACIFIC

The Asia-Pacific region installed close to 93 GW in 2021 and the total installed capacity reached more than 540 GW. The market was dynamic in all parts of Asia, (in India as well this year compared to 2020), and significant growth was recorded. In 2021 the region represented 57% of the global PV installations.

As the most populated continent, Asia was poised to become the largest PV market globally and this happened relatively fast. Apart from the dynamism of China and Japan for several years now, Asia is home to several IEA-PVPS additional GW-scale markets: Australia, Korea, and also Thailand. 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.

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 would be at least at the level of China, or more, given the need for electrification. The Indian market developed in the last years but plateaued around the 10 GW mark on an annual basis, before going down to 4,4 GW in 2020 due to a series of administrative issues and difficulties. Some policy changes such as tariff ceilings and safeguard duties in combination with a falling currency also impacted the tendering procedures. In 2018 and 2019, several tender procedures found very few bidders and even not enough takers in some cases. The support of the federal government in India for PV is obvious, especially now that the government raised its renewables ambition to 225 GW towards 2022 (and 100 GW for PV), but the road to a fast development implies additional policy changes. In 2021, the PV market in India was reinvigorated with 13,7 GW installed leading to a cumulative capacity of 61 GW. The International Solar Alliance (ISA) initiated by India and France and supported by more than 120 countries aims to install 1 000 GW in its member (emerging) countries by 2030.

In Vietnam, after a solar market take off in 2019 with over 5,2 GW installed (and a total installed capacity of 5,3 GW) and a boom in 2020 with at least 11,1 GW installed (mostly rooftop applications but also of utility-scale plants (including floating PV applications)), the marker shrunk to 2 GW in 2021 pushing the total installed capacity to 18,4 GW. The government target for 2030, 12 GW, is already reached, much faster than expected, while the country's electricity demand is expected to soar in the coming years.

In 2021, Taiwan (Chinese Taipei) installed about 1,9 GW a steady growth compared to previous years. It now reaches around 7,7 GW of cumulative capacity. The market is supported by a FiT scheme guaranteed for 20 years. Larger systems and ground-mounted systems must be approved in a competitive bidding process. The FiT level is higher for floating PV and the projects employing high-efficiency PV modules.

In addition to these three countries where installations reached GW-scale levels, the market is dynamic in several other Asian countries, with the market being driven by utility-scale applications under tenders for instance in Indonesia, the Philippines, Nepal or Kazakhstan.

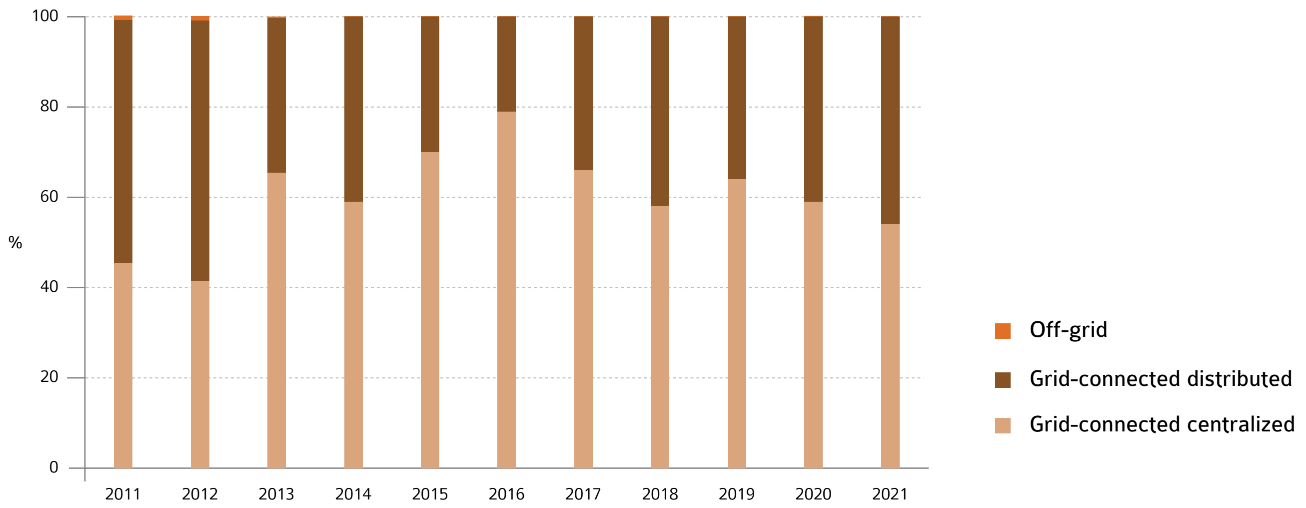
The Government of Bangladesh has been emphasizing the development of solar home systems (SHS) and solar mini-grids since about half of the population has no access to electricity. Thanks to the decrease in prices of the systems and a well-conceived micro-credit scheme, off-grid PV deployment exploded in recent years. The country targets 3,2 GW of renewables by 2021, out of which 1,7 GW of PV.

The market is growing in several other countries, at a different speed, such as in Pakistan, where the government has published a target of 5 GW of solar power by 2022, therefore, more projects are expected to come online in the coming years.

Last but not least, in Singapore, the total PV installed capacity was 630 MW at the end of 2021.

Asia is a continent so diverse, that it can be difficult to derive trends from PV market development: however, the dynamics are positive and while the challenges, as seen in India, are numerous, a massive PV market suitable for energy transition goals is coming. In that respect, Asia will continue to dominate the PV charts and pave the way for larger adoption of PV globally.

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



SOURCE IEA PVPS & OTHERS

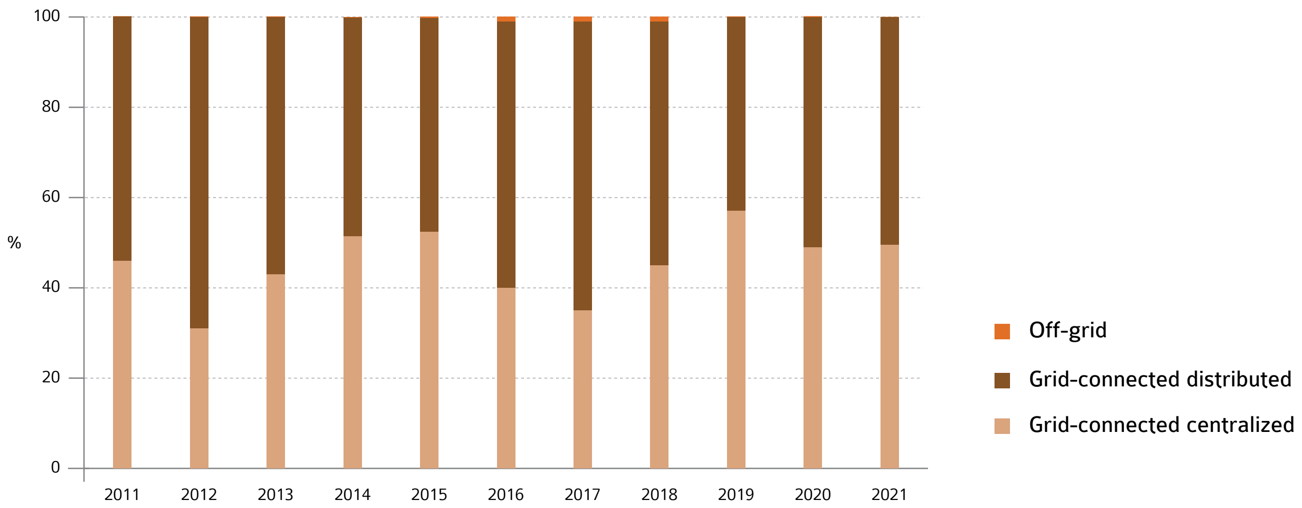
EUROPE

In the first years of this century, Europe led PV development for years and represented more than 70% of the global cumulative PV market until 2012. From 2013 to 2017, European PV installations decreased while there has been rapid growth in the rest of the world, mainly in Asia and the Americas. The fast development of PV led to a strong opposition from many stakeholders from the energy sector, and the market declined rapidly in several countries. In addition, several countries implemented measures aiming at decreasing the cost of PV installations for the community 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 developers and prosumers.

But since then, the situation improved gradually in most countries and PV installations rose in Europe. This was the case again in 2021. Europe saw its PV market growing again in 2021, with 30,9 GW installed, which accounted for 18% of the global PV market. European countries had close to 198 GW of cumulative PV capacity by the end of 2021, 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.

Most European countries used Feed-in Tariffs schemes to start developing PV and moved in the last years to self-consumption (or variants) for distributed PV while tenders became the standard for utility-scale PV. These trends are not typical to Europe, but self-consumption developed faster here than in other locations. Collective and delocalized self-consumption are developing in several countries. 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. Merchant utility-scale PV developed in Spain and Germany and could lead to a significant market share in a near future. Portugal saw competitive tenders below a reasonable price in 2020, sign of speculation on grid connections. In general, PV development in Europe has experienced a significant acceleration, and rising electricity prices in 2022 are increasing the competitiveness of PV electricity.

FIGURE 2.18: EVOLUTION OF PV INSTALLATIONS IN EUROPE PER SEGMENT



SOURCE IEA PVPS & OTHERS

European Union

Policy Framework

The European Union has a strong influence on climate and energy policies and has historically supported high renewable energy developments to tackle climate change. In recent years, the EU has set increasingly ambitious goals, which have been augmented several times: In December 2018, the revised European Renewable Energy Directive (RED II) set a 32% renewable energy target by 2030, up to 20% in comparison with 2020. Since then, the target has been increased: the share of renewables in the EU's final energy consumption has been set to 45% by 2030.

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. One of the pillars of the European Green Deal is a commitment to be climate neutral by 2050. The European Commission raised the 2030 climate targets to 55% GHG reduction by 2030.

In May 2021, the European Council received a formal notification about the approval of the Recovery and Resilience Facility (RRF) by all Member States. Together with the next long-term budget, this represents EUR 2,02 trillion of spending between 2020 and 2027 which can be partially used to develop renewables including local manufacturing: Each recovery and resilience plan has to include a minimum of 37% of expenditure earmarked for actions to fight climate change.

The recovery and resilience plans do not themselves set new targets for the deployment of renewables at a national level. Rather they define a package of strategic projects, ranging from technological to socio-economic and administrative. Most national recovery and resilience plans include measures to support the installation of solar PV systems and targets for green hydrogen from renewable energy sources. This comprises the electrification of transport mentioned in various plans that will require additional renewable electricity capacities. Rooftop installations are mentioned by several countries, often with regard to building renovation. However, total numbers are often difficult to derive as PV and wind are often bundled.

In 2022, the REPowerEU has been proposed as a joint European action for more affordable, secure, and sustainable energy: it has been deemed as necessary both to accelerate the energy transition and to secure the EU's energy supply and disconnect Europe from Russian gas and oil imports. REPowerEU includes short and medium-term milestones which aim at a full independence from all Russian energy imports by 2027. The plan would bring the total renewable energy generation capacities to 1 236 GW by 2030, in comparison to the original "Fit for 55" 1 067 GW planned by 2030. Also, as part of the REPowerEU plan, the EU Solar Energy Strategy's aim is to boost the roll-out of photovoltaic energy. This strategy aims to bring online over 320 GW of solar PV capacity by 2025, and almost 600 GW by 2030. This plan will be paving the way for an era of renewable energy at affordable prices while accelerating their development. It aims at achieving energy savings, produce clean energy and diversify the EU's energy supply sources.

The Cypriot Recovery Plan includes investments into an "Euro Asia Interconnector" in the territory of Cyprus. The Euro Asia Interconnector is a cross border interconnector between Crete, Cypriot, and Israeli power grids. The realisation of this 1 208 km long interconnection would allow more PV electricity capacity without additional storage. In March 2021, Cyprus, Greece and Israel signed a memorandum of understanding for the interconnector with a power capacity between 1 000 to 2 000 MWac. It is expected that the connection will be completed by 2024, with operations starting in 2025.

The implications for new PV capacity in the three partnering countries are significant. Different to its partners Cyprus has not yet revealed the planned additional renewable electricity capacity. Israel announced that the interconnection would allow an additional installation of 12 to 15 GW PV capacity by 2030. Greece decided to phase out coal by 2028 and add an additional 5 GW of PV capacity by 2030. To do so, a strong interconnection as well as the announced energy storage framework are crucial.

In March 2021, Hungary announced to close its last coal fired power plant 5 years earlier in 2025. This could lead to an increase of PV deployment, meaning that the 2030 target of 6,5 GW can be reached earlier. To what extend the 2040 target of 12 GW of PV systems will be brought forward is not yet clear.

The Polish recovery plan mentions rooftop PV but includes no concrete target. However, together with the Polish hydrogen strategy, which aims for 2 GW of electrolysers and the aim to replace coal heating system in residential buildings with heat pumps, will drive the demand for renewable electricity. The Polish Institute of Renewable Energy, responsible for tracking the capacity additions in the country, forecasts that the cumulative installed capacity will exceed the NECP target in 2022 and could reach 15 GW by 2025 and over 20 GW by 2030.

In Turkey, systems below 1 MW fall under the category of "non licenced plants" which allowed the market to take off. At the end of 2020, the cumulative capacity had exceeded 9,5 GW, most of it in the category of "non-licenced" according to the Turkish transmission operator. In May 2019, the Turkish Energy Market Regulatory Authority (EPDK) published new rules for net metering of PV systems with a capacity between 3 and 10 kW. Also, in May 2019, the Turkish Government amended the rules for "non licenced plants" increasing the project size up to 5 MW. However, only public installations used for agricultural irrigation, water treatment plants or waste treatment facilities are eligible as ground mounted projects.

State of Play

At the end of 2021, the total installed PV power capacity in the European Union had surpassed 170 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. This trend continued in 2021 when the European Union added upward of 28,7 GW of new PV power capacity. Spain (4,9 GW), Germany (5,8 GW), Poland (3,7 GW), the Netherlands (3,6 GW) and France (3,4 GW)can be mentioned as leading countries. Greece added over 1 GW while eight countries added more than 500 MW, namely Hungary, Austria, Denmark, Belgium, Italy, Portugal, Switzerland and Sweden.

Over the last few years, the number of European Member States conducting auctions for solar energy has continuously increased and driven down prices to the current average level of EUR 35/ MWh and EUR 70/MWh across the European Union. In 2020, the second Portuguese auction attracted the lowest bids. The winning projects offered electricity between EUR 11,2/MWh.

Other European Countries

Outside of the IEA-PVPS network, UK installed 730 MW in 2021, still far from the GW-scale market it used to be a few years ago. The country had more than 14 GW of PV at the end of the year 2021, 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 2021 about 200 MW of new PV capacity was installed in Russia, increasing the total capacity to slightly above 2 GW.

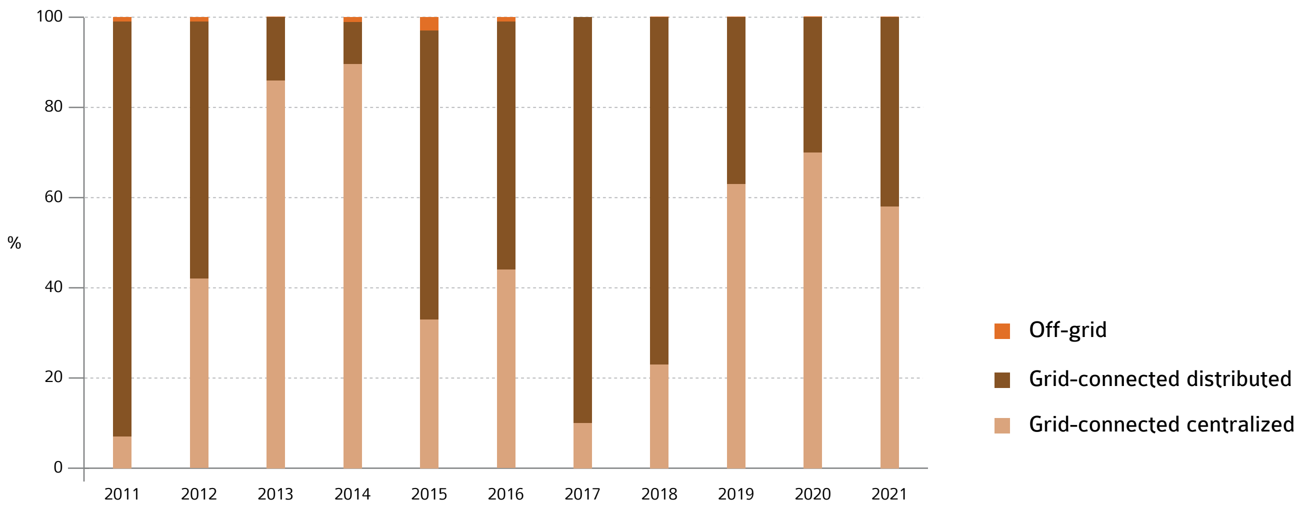
MIDDLE EAST AND AFRICA

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. Several countries are defining PV development plans and the prospects on the short to medium term are positive. 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. In 2021, around 6 GW have been installed in the region, representing 3,5% of the global market.

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 years and some of them a significant increase. There is a clear trend in most countries to include PV in energy planning, to set national targets and to prepare the regulatory framework to accommodate PV.

Next to IEA-PVPS countries with a dynamic market such as Israel and more recently Morocco, the region's PV development is extremely diverse with Egypt, Saudi Arabia and the UEA leading installations. In the middle East, the market has been driven mostly for competitive tenders for years and distributed applications started to develop only recently (net metering policies have been implemented in Israel, Jordan, Saudi Arabia and Tunisia).

FIGURE 2.19: EVOLUTION OF PV INSTALLATIONS IN AFRICA AND THE MIDDLE EAST PER SEGMENT



SOURCE IEA PVPS & OTHERS

Often, energy prices are supported by government spending, which limited for years the ability of PV to compete. This situation is changing slowly, with new distributed schemes being proposed such as in Dubai (UAE). Tenders are still competitive and Saudi Arabia became early 2021 the country with the most competitive tender: the lowest acceptable bid reached 10,4 USD per MWh, the lowest on record.

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).

The situation is similar in northern Africa, with tenders driving PV market development in Egypt (even if the development was slower than expected), Algeria, and Morocco. 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, especially in Morocco and South Africa.

In the Middle East, countries such as Saudi Arabia, Bahrain, Jordan, Oman and the United Arab Emirates have defined targets for renewable and solar energy for the coming years. Tenders are an integral part of the plans for PV development in the short or long term in the region, while several were organized again in 2019 and 2020 and more have been announced. Almost 3 GWdc have been installed in the UAE through several plants and more is expected to come.

Jordan is aiming for 1 GW of PV in 2030 and already launched several tenders and installed several hundreds of MW. Qatar published the results of its third tender for 800 MW in January 2020. Saudi Arabia launched a series of tenders in the past and has again in 2020, with an initial objective totalling 3,3 GW. Bahrain has announced the development of 225 MW; Oman has launched several tenders, each for at least 500 MW and plans to reach 4 GW of RES capacity by 2030, Tunisia launched a tender for 500 MW and for 70 MW, Libya 100 MW. Lebanon plans 180 MW towards 2020 and is investigating a plant of 500 MW as well.

In Sub-Saharan Africa, with the notable exception of South Africa, the market has been slower to develop. Development Aid is often a key tool for financing hybrid PV systems and electrify directly through new grid connection. Egypt is the new African market leader with close to 300 MW installed in one year. The policies engaged for several years now have started to produce positive effects and the market is poised to develop further.

South Africa was the first major African PV market, under several tenders that led to 4,6 GW cumulatively installed at the end of 2021. While a large part of the market was driven by tenders, the market should rebalance towards rooftop applications in the coming years under government support.

In Africa, besides the above-mentioned countries, Algeria has installed several hundreds of MW. Reunion Island, Senegal, Kenya, Mauritania, Namibia and Ghana have already installed some capacity. As the costs are decreasing, the interest in PV is growing in other African countries. However, the market has not really taken off despite the huge potential and the growing competitiveness of solar PV, especially in off-grid applications. The main barrier is the financial aspect as the higher upfront investment costs remains a barrier despite lower LCOE.

The most competitive segment for the development of solar in Africa, especially in remote areas, is PV plants to replace or complement existing diesel generators. Such kinds of hybrid plants have been developed in Democratic Republic of Congo, Rwanda, Ghana, Mali, Ivory Coast, Burkina Faso, Cameroon, Gambia, Mauritania, Benin, Sierra Leone, Lesotho and others.

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.

Several large-scale PV plants have been announced or are under construction in several countries in Africa: Burkina Faso (20 MW and 30 MW), Namibia (45 MW and 30 MW), Nigeria (100 MW), Cameroon (30 MW and 25 MW projects ongoing) and Kenya (several projects ranging from 30 MW to 80 MW) to name just a few. The question of African power markets is essential since many countries have a small, centralized power demand, sometimes below 500 MW. In this respect, the question is not only to connect PV to the grid but also to reinforce the electricity grid infrastructure and interconnection with neighbouring countries. However, concerning remote areas, micro-grids and off-grid PV applications, such as water pumping installations, are expected to play a growing role in bringing affordable power to the consumers, in a continent with 700 million people still lack a basic access to electricity.

TABLE 2.6: 2021 PV MARKET STATISTICS IN DETAIL

COUNTRY	2021 ANNUAL CAPACITY (MW)			2021 CUMULATIVE CAPACITY (MW)		
	DECENTRALIZED	CENTRALIZED	TOTAL	DECENTRALIZED	CENTRALIZED	TOTAL
AUSTRALIA	**3 231**	1 713	4 944	17 037	8 998	26 035
AUSTRIA	**658**	81	739	2 679	104	2 783
CANADA	**118**	304	421	1 533	2 602	4 135
CHILE	**1 250**	1 431	2 681	1 323	4 842	6 165
CHINA	**29 280**	25 600	54 880	108 580	199 940	308 520
DENMARK	**271**	447	718	1 514	830	2 344
FINLAND	**95**	5	100	408	5	413
FRANCE	**1 133**	2 219	3 350	8 734	7 716	16 450
GERMANY	**3 753**	2 008	5 760	48 559	11 103	59 661
ISRAEL	**668**	267	935	1 939	1 410	3 349
ITALY	**890**	54	944	14 546	8 048	22 594
JAPAN	**3 553**	2 992	6 545	48 292	30 121	78 413
KOREA	**228**	3 997	4 225	2 640	189 08	21 548
MALAYSIA	**301**	69	370	728	1 603	2 330
MEXICO	**825**	801	1 625	2 040	6 159	8 199
MOROCCO	**-**	-	493	-	-	699
NETHERLANDS	**1 287**	2 345	3 632	5 861	8 488	14 349
NORWAY	**45**	0	45	205	0	205
PORTUGAL	**102**	469	571	569	1 079	1 647
SOUTH AFRICA	**58**	400	458	1 058	3 572	4 630
SPAIN	**1 400**	3 500	4 900	3 277	15 226	18 503
SWEDEN	**576**	23	599	1 690	108	1 798
SWITZERLAND	**615**	68	683	3 431	226	3 656
THAILAND	**250**	250	500	900	3 178	4 078
TURKEY	**845**	647	1 492	9 735	1 182	10 917
UNITED STATES	**6 618**	20 255	26 873	42 677	80 327	123 004
IEA PVPS	**58 797**	69 978	129 267	335 552	417 642	753 891
NON-IEA PVPS	**19 319**	25 373	44 200	75 802	116 697	191 801
TOTAL	**78 116**	95 351	173 467	411 354	534 339	945 692

SOURCE IEA PVPS & OTHERS

Photo by Denis Schroeder, NREL 60075

three

POLICY FRAMEWORK

In the early phase of PV development, most markets have been powered by a broad spectrum of support policies, from feed-in tariffs and direct subsidies to competitive calls for tender and premiums. The first aim was to reduce the gap between PV's cost of electricity and the price of conventional electricity sources thanks to financial support. The rapid price decline that PV experienced in the last years has enabled PV systems to reach competitive prices in several segments and countries (for more detail, see Chapter 6, competitiveness of PV electricity). The possibility to develop PV systems in many locations with limited or no financial incentives is now an observable reality. Direct long-term private contracts between PV plant owners and off-takers for the electricity produced (PPAs), and the sale of electricity on wholesale markets (merchant PV), have seen in an increasing number of countries in 2021 (a large part of ground-mounted PV plants installed capacity in Spain in 2021 was developed through PPAs). The growing competitiveness of PV electricity has also boosted the share of non-incentivized self-consumption PV installations, which have reached 6% in 2021. Moreover, the increase in energy costs in 2021 and 2022, and specifically electricity prices, have enhanced PV competitiveness in numerous countries. If high market prices for electricity remain, the question of competitiveness will change completely as will the way to conceive PV market support and policy framework. Without any support scheme limitation, the PV market potential looks virtually unlimited.

However, the competitiveness of PV is not yet guaranteed in all segments and locations. Therefore, targeted financial incentives might still be needed for some years to overcome costs or investment barriers in specific countries. Support schemes are evolving according to market maturity, PV electricity competitiveness and investor confidence. Predefined feed-in-tariffs that support centralized PV are being replaced in many countries by auctions with calls for tenders to propose the most competitive PV electricity. This mechanism can be adapted, setting the same auctions but for a variable premium, given on top of the wholesale market price where the electricity is sold. When no more incentive is needed, PV plants selling electricity through PPAs can be setup followed by plants that sell electricity directly to the market.

Support for the distributed PV market often begins by setting feed-in tariffs too, which still support half of these segments in 2021 (54%), even if the trend leans towards lower tariffs. In places where self-consumption is incentivized, supported initially by net-metering mechanisms turning to net-billing mechanisms, premiums or FiT tariffs for the excess electricity fed into the grid before competitive self-consumption without any incentives can take place.

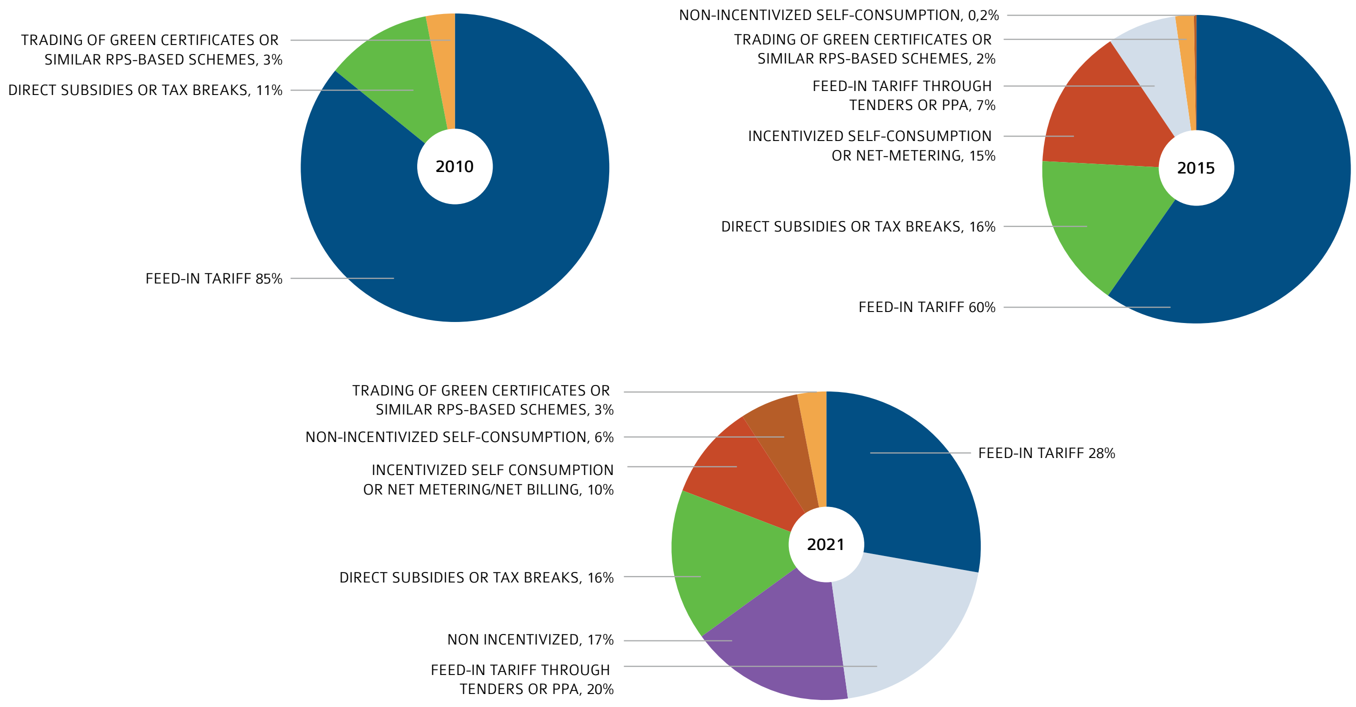
Since the question of the competitiveness of PV is less pressing, a large part of new policies is also focussed on self-consumption schemes, citizen communities and innovating forms of collective and delocalised self-consumption. Policies supporting self-consumption might be considered as non-financial incentives since they set up the regulatory environment to allow consumers to become prosumers or an energy community. 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 the business models and the price for PV electricity to compete.

In addition to direct policies supporting PV development, other indirect policies have a tremendous effect on PV development. Sustainable building requirements, for instance, will become increasingly essential to support a long-lasting PV market development even if most of the time the requirements are technology agnostic. Electric vehicle development roadmaps will also have a direct impact on electricity demand, as well as hydrogen production. Cross-sectoral aspects of PV development will also imply that PV will be submitted to additional regulations and policies, in the building and transport sector, but also in agriculture, the urban environment, water areas (including the seas), industrial process and more...

With the share of PV electricity growing in the electricity system 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.

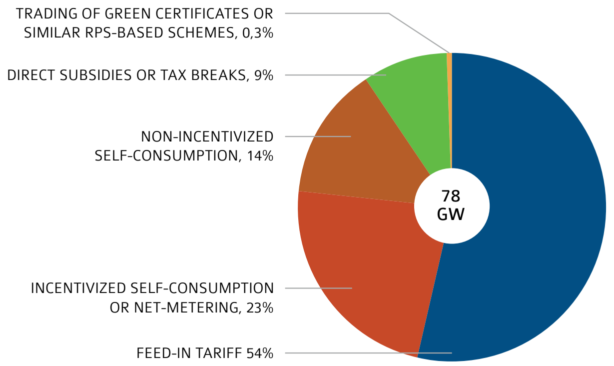
Today, climate policies have an indirect effect but are shifting the competitiveness of renewable energy sources upwards.

FIGURE 3.1: EVOLUTION OF MARKET INCENTIVES AND ENABLERS: 2010, 2015, 2021



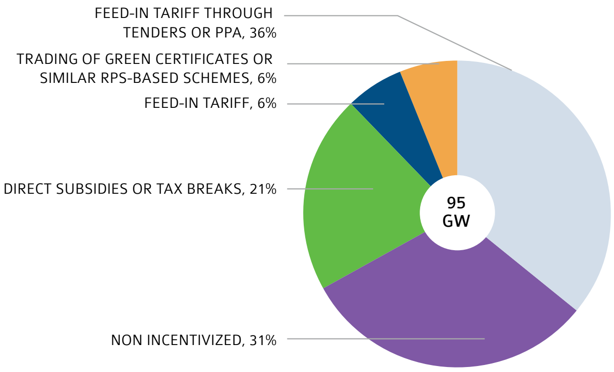
PV MARKET DRIVERS AND SUPPORT SCHEMES

FIGURE 3.2A: MAIN DRIVERS OF THE DISTRIBUTED PV MARKET IN 2021



SOURCE IEA PVPS & OTHERS

FIGURE 3.2B: MAIN DRIVERS OF THE CENTRALIZED PV MARKET IN 2021



SOURCE IEA PVPS & OTHERS

The question of market drivers is a complex one since the market is always driven by a combination of several regulations and incentives. In these figures, the focus is put on the major driver for each macro-segment (distributed or centralized), while other drivers are playing a key role. This should be regarded as a general indication of the main PV drivers.

FEED-IN TARIFFS

Globally, about 28% of the PV installations are receiving a predefined tariff for part or all of their production; respectively 54% and 6% for the distributed and the centralized segments. There is a global trend towards lower tariffs. This decreasing FiTs are in line with the price decrease of the PV technology. The increase seen in 2021, although possibly temporary, might put the brakes on the tariffs decline.

The concept of FiT is quite simple. Electricity produced by the PV system and injected into the grid is paid at a predefined price and guaranteed during a fixed period. FiT are paid in general by official bodies or utilities in order to set-up a PV market segment. In theory, the price could be indexed on the inflation rate, but this is rarely the case. The FiT model generally assumes that a PV system produces electricity for injecting into the grid rather than for local consumption. However, a FiT can be used to incentivize self-consumption projects through a remuneration for the excess electricity injected into the grid.

Amongst the IEA PVPS members many countries had a FiT scheme in 2021, in most cases to support the residential market (Australia, Canada, China, France, Germany, Japan, Portugal, Switzerland) The attractiveness of FiT has been slightly reduced compared to the early developments of PV but so far it still represents a major driver of PV installation, although some countries announced a phase-out (such as Austria in 2021, Kenya in 2022). Depending on the country specifics, FiT can be defined at the national level and at the regional, county or city level (Australia, Canada, China, etc.) with some regions opting for it and others not, or with different characteristics. FiT can also be granted by utilities themselves (Switzerland), outside of the policy framework to increase customer fidelity.

FiT remains a very simple instrument to develop PV, but it needs to be fine-tuned on a regular basis to ensure a stable market development. Indeed, the market can grow out of control if there is an imbalance between the level off the tariffs and the effective cost of PV systems, especially when the budget available for the FiT payments is not limited. Most market booms in countries with unlimited FiT schemes were caused by the unpredictable steep price decrease of PV systems, while the level of the FiT was not adapted fast enough. This situation caused the market to grow out of control, mainly in early markets in European countries. The market booms occurred in countries such as Spain in 2008, Czech Republic in 2010, Italy in 2011, Belgium in 2012, to a certain extent in China in 2015, 2016 and 2017, and to a lesser extent to other countries. Unfortunately, these booms have strained the budget and negatively affected the public perception of PV, most of these markets took years to recover and reexperience growth.

PV MARKET DRIVERS AND SUPPORT SCHEMES / CONTINUED

Therefore, 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 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 - and has been put in place retroactively in July 2022.

FiT remains the most popular support scheme for grid-connected PV systems; especially for small household rooftops applications. The ease of implementation continues to make it the most used regulatory framework for PV globally.

FEED IN TARIFF AND PREMIUM THROUGH TENDERS

Calls for tenders are another way to grant FiT schemes with an indirect financial cap. This system has been adopted in many countries around the world, with the clear aim of increasing the competitiveness of PV electricity. Around 36% of utility-scale plants were developed through tenders: this is a significant increase which started a few years ago. The relevance of this scheme for a distributed segment can be questioned and tenders experimented in some countries for the smallest capacities have generally not been renewed, like in France.

Tenders have gained success in the entire world over the last few years and Europe is aligned with this trend. In Australia, solar tenders come from a mix of state and local governments and electricity retailers. In the Middle East and North Africa, tenders were issued in Egypt, Israel, Jordan, Morocco, South Africa, Qatar, Koweit, and the UAE. In the rest of the world, many others have joined the list of countries using calls for tenders. In Latin America, Argentina, Brazil, Chile, Mexico, and Peru, just to mention the most visible, have implemented such tenders. In Asia, India, Nepal and Sri Lanka also started to launch tenders, while in Southern Africa, Nigeria, Senegal, Tunisia, and Malawi can be cited amongst the newcomers.

Impact of competitive tenders on the market

Tenders have driven PV development in the last years and continued to be granted in several places in the world with extremely competitive prices, well below 20 USD/MWh in the sunniest places. Winning bids down to almost 10 USD/MWh have been reported in the Middle East, while some tenders with prices below 14 USD/MWh have been recorded in Europe (but these can be questioned). The decreasing price trend halted in 2021 due to module price hikes, and most experts believe that prices will hardly continue to go down in the coming years, at least until the raw material crisis can be solved. Since bidders must compete with one another, they tend to reduce the bidding price to the minimum possible and shrink their margins. This process is currently showing 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. This is already visible in 2021 with the major increase of prices due to the impact of the pandemic, which results in huge difficulties for some developers to remain competitive on already granted tenders. Therefore, it is conceivable that they do not represent the average PV price in all cases but are showcases for super-competitive developers.

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 are experimenting with mixed auctions based on solar and wind in parallel with some technology-specific tenders. Tender can also be set to reach a capacity as it has been experimented in Mexico.

In some countries, cost-based tenders evolve towards multiple-factors 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 like in some African countries such as Algeria, Morocco and South Africa. This type of requirement aims at enabling the development of local solar module manufacturing. Turkey, for instance, applies a premium for local content, on top of the normal FiT. In the USA, a tax rebate bonus is granted.

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.

Towards variable feed-in premium or "contract for difference"

In several countries, the FiT schemes awarded by auctions are being replaced by feed-in premiums. The premium is 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 decentralized systems. In Germany, France, Italy and the Netherlands, the remuneration of solar PV 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 so-called Contract for Difference scheme is a FiP that ensures constant remuneration by covering the difference between the expected remuneration and the electricity market price. It also can generate reversed cash flows between generators and governments since late 2021 and the explosion in market electricity prices.

Tenders have not yet shown their full potential. For the time being, they are mostly used to frame PV development and PV costs. For regulators, this implies defining a maximum capacity and proposing the cheapest suitable plants to develop. However, it could be developed further and be part of a larger, long-term, roadmap on power capacity development. By planning smartly, together with transmission grid operators, tenders could allow to develop specific capacities for defined technologies, optimize the grid and plan smartly the energy transition to be an instrument to support local industry.

INCENTIVIZED SELF-CONSUMPTION

Self-consumption, supported by different mechanisms such as net-metering and net-billing, represented 23% of the distributed PV market, an important increase compared to historical installations. 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, however, with different definitions. One must be careful when looking at self-consumption schemes since the same vocabulary can imply different regulations depending on the case. 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, Korea and the USA, but such policies are increasingly replaced by self-consumption policies favouring real-time consumption of PV electricity, 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 and in France. 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 AND TAX BREAKS

With around 16% global market share, 9% for the distributed segment and 21% of the centralized segment, 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. 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, Korea, Lithuania, Norway, and Sweden just to mention a few. In most countries this support mechanism has not demonstrated its ability to support and accelerate PV development and was replaced by FITs. In others countries a trend to reintroduce to this mechanism seems to be observed. In others countries a trend to reintroduce this mechanism seems to be observed. For instance in Canada, the province of Alberta introduced a capital incentive program for commercial PV while the federal government introduced one for homeowners. In Austria in 2021, the FIT came to an end, and either a market premium or an investment subsidy can support a PV system. This return to subsidies could be questioned. Subsidies are a constraint to PV development because they depend on public funding, which is, by nature, limited. However, they are easy to set up which explains their utilization.

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. 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.

Tax credits have been used in a large variety of countries, ranging from Belgium, Canada, Japan and others. Italy uses a tax credit for small size plants. The debate was also intense in the USA in 2015 when extending the ITC (Investment Tax Credit), where tax rebate is the main driver. In Sweden, the direct capital subsidy for PV installations expired in 2020 replaced by a tax reduction program. In Italy a new tax credit in the field of building energy efficiency interventions including PV has been introduced.

TRADE OF GREEN CERTIFICATES AND SIMILAR SCHEMES

Green certificates and similar schemes based on Renewable Portfolio Standard" (RPS) represented around 3% of the market, a stable and low share which is explained by the greater complexity of this type of scheme. Green certificate trading still exists in countries such as Belgium, Norway, Romania and Sweden. Similar schemes based on RPS exist in Australia and Korea for instance. 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. This system exists in various forms. State incentives in the USA have been driven in large part by the passage of Renewable Portfolio Standards (RPS). Different multipliers are applied to floating PV. In Belgium, all three regions use the trading of green certificates for commercial and industrial segments.

PV DEVELOPMENT WITHOUT FINANCIAL INCENTIVES

Figure 3.1 shows that in 2021, around 23% (6% and 17%) of the 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 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, during a defined period. Such contracts allow to guarantee a certain level of revenues and are increasingly popular for unsubsidized PV. Such contracts are mainly deployed in the wind industry for the moment, while their potential for PV remains largely untapped. The European Union incites member states to remove administrative barriers to long-term PPA and to facilitate their adoption.

Electricity sold on electricity markets or through PPAs has been seen in an increasing number of countries in 2021. Non-subsidized models are gaining momentum for utility-scale PV. The trend is clear, PV plants selling their production to corporate customers have emerged. Spain is probably leading the PPA market, if not worldwide, at least in Europe. Over the last years, more and more bilateral PPAs were signed between producers and consumers and a large part of the ground-mounted installed capacity in 2021 in Spain, 3,5 GW, was developed through PPAs. The reduced LCOE allows new market segment development, more recently unsubsidized PPAs also appears in Korea, Denmark, Germany, Italy, and Sweden. From 2022 onwards, the utility-scale segment is developing under unsubsidised market conditions in Sweden. The USA and Australia are also markets where PPAs are gaining market shares. In California, many PPAs, sometimes with record low prices, were approved over the last years. 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.

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.

Non-incentivized Self-consumption

The PV system will be considered fully competitive when the revenues from the savings on the electricity bill (the self-consumed part) and the revenues from the sales of excess PV electricity will cover over the long-term the cost of installing, financing and operating the PV system. In most cases, the price of retail electricity will be higher than the wholesale price. Distributed PV evolves rapidly towards a competitive market, where new players and especially traditional utilities start to play a leading role

The question of grid costs for instance becomes more important with rising PV penetration and is already leading in some countries to specific tariffs which are reducing the competitiveness of distributed PV installations. The arrival of new schemes based on the energy communities' concepts could enlarge the market but also increases complexity while in some countries the joined PV with storage trend (such as in Germany) also paves the way for a different way of looking at PV development for distributed installations.

Innovating Financial Solution Support

An increasing number of investment solutions have emerged for the financing of solar installations, these are even more relevant in the case of unsubsidized PV. The high upfront capacity 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, as we will see below. However, the US case is innovative by the existence of pure players proposing PV as their main product. Since it solves many questions related to financing and operations, as well as reducing the uncertainty in the long-term for the prosumer, it is possible that such services will further develop, along with the necessary developments which will push up distributed PV.

Similarly, the 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.

PROSUMERS AND ENERGY COMMUNITIES' POLICIES

SELF-CONSUMPTION IN REGULATORY ENVIRONMENTS

In recent years self-consumption regulations are increasingly being implemented in different countries; the aim is to empower prosumers to play an important role in the energy transition. 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. Sometimes with an ad hoc legal framework, sometimes without. The very principle of self-consumption is always the same: the electricity that is produced by the PV system and locally consumed reduces mechanically the electricity bill of the consumer. But 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. In a more general way, several countries have either modified the structure of the grid tariffs (to increase the fixed part and reduce the variable part linked to the consumption). In Australia and France, 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 PV development. In the USA, an intense debate on the cost of net-metering policies led to small grid costs increases for prosumers. The case of Israel is more specific, with dedicated taxes for balancing and back-up. Specific grid taxes are starting to be implemented in some countries, with the aim to compensate for saved grid costs due to net-metering policies. 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 benefitting from net-metering which allows full compensation of their PV consumption, grid cost included.

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 imposes specific grid codes. Germany requires specific compliance with specific grid codes for all PV systems. Other countries have imposed specific grid codes as well. In most countries, the ownership of the PV system can differ from the electricity consumer. This is a complex situation with national regulations and no clear pattern appears today regarding third-party ownership.

While most countries accept self-consumption schemes for PV systems installed on consumption sites, some specificities exist in various parts of the world. Different forms of collective self-consumption, both local and delocalized, are being implemented.

COLLECTIVE SELF-CONSUMPTION

Collective self-consumption enables the sharing of electricity between several users, but also under some conditions, 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. 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 or Italy to mention a few. Decentralized or distributed self-consumption is developed with the aim of disconnecting production and consumption of PV electricity. This would allow 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. Such disconnection between production and consumption would help to alleviate the constraint of the local self-consumption ratio, and the constraint of non-PV suitable roofs and allow for better use of available space on roofs or land.

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 savings on the electricity bill can be decreased if grid taxes or levies are to be paid on the self-consumed electricity. Fixed or capacity-based grid tariffs can also have a detrimental effect on the revenues for the prosumers.

In Italy, since 2020 a measure allows consumers in the same building or in a "energy community" to share electricity and the reform of the law is underway, which will make it possible to set less stringent limits for participants. In Sweden, it had been allowed in 2021 for multi-family houses. In France since 2021, virtual self-consumption within a building, a 2 km, or exceptionally, a 20 km geographical perimeter is allowed and FIT for excess electricity. 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. Other countries have definitions but these are not yet fully implemented. In Austria, collective self-consumption was introduced a few years ago, but by the end of 2021, only hundreds of projects were recorded as it is frequently not seen as a sufficient financial benefit by the users as in the other pioneer countries. These trends will maybe reverse if high retail prices of electricity remain and with the introduction of energy communities.

In Australia, the support program closed in 2021. Current network pricing regulations in Australia 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. Micrograds that include PV operate across the country, particularly in new housing developments and in power supplies for remote communities. In Switzerland collective self-consumption is allowed by most DSOs, consumers have to be contiguous, the public grid is not used the internal metering is then under the responsibility of the consortium. In the USA, community microgrids are emerging to reduce the cost of electricity consumption and provide local resilience through storage and backup power.

ENERGY COMMUNITIES IN THE EU 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 recasts 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. 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.

DELOCALIZED OR "VIRTUAL" SELF-CONSUMPTION

While self-consumption could be understood as the compensation of production and consumption locally, decentralized (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. Some utilities even launched pilot projects before the 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 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 nearby a village to power it. Options are numerous and imply fair remuneration of the grid to be competitive for all. Using PV electricity in a decentralized 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.

To better compare existing and future self-consumption schemes, the IEA PVPS published a comprehensive guide to analyse and compare self-consumption policies. This "Review of PV Self-Consumption Policies" proposes a methodology to understand, analyse and compare schemes that might be fundamentally diverse, sometimes under the same wording. It also proposes an analysis of the most important elements impacting the business models of all stakeholders, from grid operators to electric utilities.

ENERGY TRANSITION POLITICS

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.

European Union adopted several proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse emissions by at least 55% by 2030. 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 first of them is promoting quick and massive PV deployment via the European Solar Rooftops Initiative. That can strongly influence the decentralized market in European Union states.

For instance, in France, the threshold for mandatory solar or living roofs for commercial and industrial buildings or covered car parks have been decreased. Actual thermal regulations, and incentive high-performance building labels encourage photovoltaics and self-consumption. In Austria, many counties have regulations or incentives for building a PV system. Up to now in Vienna and Styria it is obligatory to install a PV system under certain conditions. In Korea, the NRE Mandatory Use for Public Buildings Programme imposes on new public institution buildings with floor areas exceeding 1 000 square meters to source more than 10% of their energy consumption from new and renewable sources. In Belgium, Flanders introduced a similar measure since 2014. The first results show that PV is chosen in more than 85% of the new buildings. In Denmark, the national building code has integrated PV to reduce the energy footprint.

ELECTRIC MOBILITY

The development of electric mobility represents an important for the PV sector as the need for clean energy will increase. Furthermore, charging points can be coupled with solar PV on parking shelters for instance. In Europe, National and local-level actions exist to support EV deployment, an overall trend is the increasing number of European cities playing a prominent role to address market barriers to EV uptake. The aim of the cities' programs is mainly to deploy charging infrastructure in an integrated and homogenous way and to increase the visibility of EV solutions.

In Austria, the purchase of electric vehicles for private use is supported. The 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.

HYDROGEN PRODUCTION

The recent invasion of Ukraine by Russia and the international sanctions that followed, pushed gas prices upwards. This might increase the drive towards a hydrogen-based economy in Europe. Solar fuels, storage and other hydrogen-based applications will require massive PV, wind and other RES development. Distributed Hydrogen production could be driven by DPV 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, but this could start to become a business reality around 2025. The Commission 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. 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 15GW and 40 GW, on a low and high case scenario respectively, of electrolysers in Europe by 2030.

ELECTRICITY STORAGE

In the current stage of development, electricity storage remains to be incentivized to develop. 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 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 in PV systems to 2021, Austria, the subsidies support the construction, expansion and 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 state governments are now offering some type of incentive for solar plus battery installations or to add a battery to an existing solar system. In France in 2020, a tender was launched to provide low carbon flexibility for the grid, with around two-thirds of the selected projects based on storage, the rest on load shifting. This tender doubled the cumulated installed capacity connected to the medium-voltage grid. In Australia, Victoria has announced a plan for clean energy including the biggest battery in the southern hemisphere. In 2021, the market operator changed the settlement period for self-consumption from 30 minute to 5 min, providing a better price signal for investment in faster response technologies, such as batteries and gas peaking generators. There are numerous trials of virtual power plants, demand response and battery integration.

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 V2 G concepts are being explored and tested in several countries, with the Netherlands, Switzerland and Japan as front-runners.

GRID INTEGRATION

With the share of PV electricity growing in the electricity system of several countries, the question of integration to the electricity grid is becoming more acute. In some countries, temporary or permanent curtailment rules have been devised to avoid grid reinforcement or to avoid grid congestion in the meantime. In China, the adequacy of the grid remains one important question that pushed the government to favour the development of decentralized PV in the future over large utility-scale power plants. It is interesting to note that many transmission system operators are increasing the penetration of PV in their scenarios and try to assess the impact of such developments. Such scenarios and calculations have been done by many TSOs and show how important PV development starts to become.

The EU also set an indicative target of 15% interconnection towards 2030 and 93 GW additional cross-border capacity is needed by 2040 to achieve the EU Green Deal. 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.

Despite the overall benefits of grid expansion, the costs of network upgrades must still be distributed between the end users through grid tariffs, also called network tariffs. Network tariffs are designed to recover the costs of investing and operating electricity networks. Tariffs should be used to incentivise efficiency in both network use and investment. For instance, grid reinforcement is not always the most cost-efficient way to integrate RES: in some cases, local storage or demand side management might be available at a lower cost. Therefore, grid tariffs should increasingly be time-variable and location-based. Cost-reflective rate structures should provide the right incentives to develop local storage or load control. Tariffs are effective tools to drive investments, however, some objectives may require different types, sometimes incompatible, price signals or some objectives may evolve over time. Furthermore, despite the role that grid tariffs can play to give price signals to consumers, other tools exist and can be required to achieve certain goals. Therefore, the priority of grid tariffs should be to accurately reflect cost while also keeping the overall rationale transparent, future-proof and simple for consumers to understand and implement. A coherency between distribution and transmission grid tariffs is needed to avoid conflicting price signals, hence market responses that cancel each other out for instance.

By submitting PV applications to stricter grid codes and regulations, connecting PV systems to the grid becomes more complex and therefore more costly. The increased need to provide ancillary services to the grid, including frequency response for instance, and curtailment, changes the nature of the connection for the PV system and can increase prices or reduce revenues. This influences the competitiveness of PV solutions.

Grid codes have been reviewed in the European Union in an attempt to harmonise grid codes between member states and will lead to additional constraints for PV systems. In Australia, specific grid codes have been adapted for PV and more will come. In Mexico, specific grid requirements have in some cases been imposed to bidders in tendering processes. In any case, grid integration policies will become an important subject in the coming years, with the need to regulate PV installations in densely equipped areas.

Grid costs are another essential element, which deals with PV competitiveness, especially for distributed PV applications under self-consumption. Since the competitiveness of the solution depends on the ability to reduce the electricity bill of the consumer, the grid costs might affect the outcome tremendously. In particular, several countries discuss the shift of grid costs from an energy-based structure towards a capacity-based structure: this would affect significantly the profitability of distributed PV plants if all grid costs would have to be paid, even with large shares of the energy produced on site. The reason behind this originates from the loss of incomes of grid operators who see their revenues and therefore their capacity to invest and maintain the grid, being reduced significantly if prosumers or semi-independent energy communities would become the new normal.

The example of decentralized self-consumption indicates how important it will be for the grids to know their real costs and invoice prosumers with a fair tariff depending on the real use of the grids. The changing electricity landscape with the fast development of electric mobility in several countries, the development of distributed storage and the expected electrification of heating, would deserve a long-term analysis to find the right balance between the different incentives that grid tariffs ultimately provide.

INDUSTRIAL AND MANUFACTURING POLICIES

2021 has seen numerous initiatives favouring local manufacturing at various steps of the PV value chain. The increasing importance of PV in the energy sector, and its expected growth are pushing numerous governments to support local manufacturing through policies, subsidies and regulations.

While trade conflicts have diminished in intensity in the last years, the willingness to support local production has increased with initiatives in Europe, the USA, India, Morocco or Saudi Arabia. This reflects the growing perception of the importance that PV could take in the coming years and the willingness to secure strategic production in some countries.

This trend is increasing globally, often without 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.

In addition to this, the growing share of PV in the production of some components, like glass sheets for instance, starts to represent a growing share of the total production, with local and global impacts in case of shortage as seen in China in 2021. In that respect, local manufacturing will imply access to global value chains and the role of already existing global actors shouldn't be neglected.

The EU Solar Energy Strategy is part of the REPowerEU plan. By launching a European Solar PV Industry Alliance that aims to facilitate innovation-driven expansion of a resilient industrial solar value chain in the EU, particularly in the PV manufacturing sector.

four

TRENDS IN PV INDUSTRY

This chapter provides a brief overview of the upstream and downstream sectors of the PV industry, intending to summarise highlights from 2021 and the first half of 2022. The first part covers manufacturing activities of the upstream sector of the PV industry from feedstocks (polysilicon, ingots, blocks/bricks, and wafers) to PV cells and modules as described in figure 4.1 and activities of the balance-of-systems (BOS). The second part covers activities such as project development and operation and maintenance (O&M).

Throughout 2021, an increase of the prices of PV modules and other components was observed. This affected planned projects. The price level of PV modules was mostly driven by the high polysilicon price. The speed of polysilicon demand increase was higher than that of capacity enhancements. This situation continued in the first half of 2022. Other factors, such as the silver and aluminum price increase, which are respectively used for electrodes and frames, also affected the price hike of PV modules. In addition, high logistic costs also contributed to the price increase. The shortage of semiconductors also impacted inverters supply.

In 2021, 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 energy transition, risks of heavy concentration of manufacturing locations have been pointed out. Policy and measures of local manufacturing have started in various regions. Trade conflict and political stance over forced labor also backed these trends.

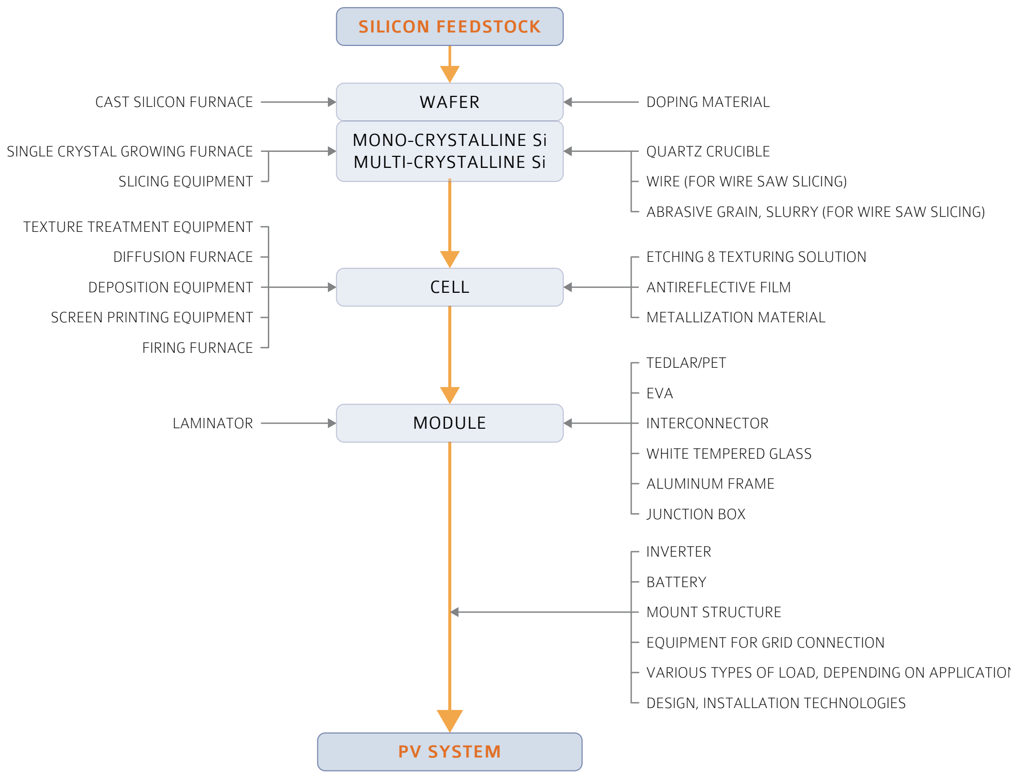
THE UPSTREAM PV SECTOR

POLYSILICON PRODUCTION

Wafer-based c-Si technology remains dominant for producing PV cells. In that respect, this section focuses on the wafer-based production process. The global polysilicon production (including semiconductor grade polysilicon) in 2021 was about 644 100 tonnes. Polysilicon used for solar cells increased from 497 300 tonnes in 2020 to approximately. 604 812 tonnes in 2021, while 39 300 tonnes of polysilicon were used for the semiconductor industry. The production volume of polysilicon for solar cells accounted for about 94% of total production of polysilicon in 2021. Figure 4.2 shows the share of polysilicon production by country.

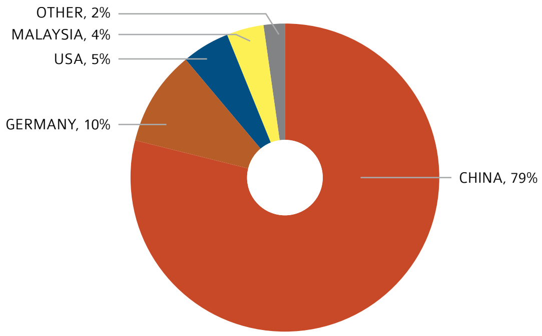
THE UPSTREAM PV SECTOR / CONTINUED

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



SOURCE IEA PVPS & OTHERS.

FIGURE 4.2: SHARE OF PV POLYSILICON PRODUCTION IN 2021



SOURCE IEA PVPS, RTS CORPORATION
* INCLUDING POLYSILICON FOR SEMICONDUCTORS

IEA PVPS member countries producing polysilicon are China, Germany, USA, Malaysia, Korea, Norway and Japan. China continued to be the largest producer and consumer of polysilicon in the world, China produced 623 000 tonnes of polysilicon in 2021, 79% of the global production. China's polysilicon production capacity accounted for 78% of the global production capacity in 2021, an increase of 3,% compared to 75,% in 2020. As was mentioned, most of new capacity addition is planned in China including new polysilicon factories by new entrants. The production capacity in 2022 is expected to reach 992 000 tonnes/year in China if all the announced plans would be implemented. The second largest producer is Germany, where 65 000 tonnes of polysilicon were produced in which almost 60 000 can be considered to have been consumed for PV production. Malaysia is the third largest producer with a capacity of, with 3 0000 tonnes/year. In the USA, most of the production was used by the semiconductor industry as in the previous year, due to the Chinese government tariffs imposed on the US-made polysilicon. Norway reported activities of polysilicon manufacturers adopting the metallurgical process aiming at lowering the production cost. In Norway, approx. 6 500 tonnes of polysilicon are estimated to have been produced in 2021. In Japan and Korea, polysilicon production is mainly dedicated to the semiconductor industry.

A supply and demand gap of polysilicon was foreseen in 2021. The polysilicon price increased from 10, USD/kg by the end of December 2020 to 29 USD/kg by the end of May 2021. In June, the Chinese Photovoltaic Industry Association (CPIA) issued a statement urging the national government to take appropriate action in response to the soaring polysilicon prices. Afterwards, the polysilicon price showed a short drop during July and August 2021 However, due to the electricity crunch that occurred and the shutdown of some polysilicon plants, the prices reached 33 USD/kg by the end of September. In 2022, the high prices maintained for polysilicon due to the demand growth and to the shutdown of several plants, because of the electricity shortage in China. By the end of 2022, the global manufacturing capacity of polysilicon is expected to reach more than 1 650 000 tonnes/year, more than double of the previous year. If the new polysilicon plants would start operations as scheduled, a stabilization of the polysilicon prices is expected after the second half of 2022.

In the first half of 2022, China produced 365 000 tonnes of polysilicon, a 53% increase from the same period in 2021. The polysilicon price remained high due to the demand growth and the gap between supply and demand. In July 2022, one polysilicon plant shut down due to an accident and several plants halted operation for regular inspection. The reported spot price of polysilicon as of the end of July 2022 reached 38 USD/kg.

With the improvement of conversion efficiency of PV cells and modules and the efforts to reduce the use of materials (thinning of wafers), the amount of polysilicon used for 1 W of wafer (consumption unit of polysilicon) has been decreasing year after year. In 2021, it is estimated that average 3,1 g/W of polysilicon was used for a solar cell, and it decreased to average 2,7 g/W in 2021. Compared to 6,8 g/W in 2010, the consumption unit of polysilicon decreased at a pace of ~9% annually.

Most of 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 process 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 66,5 kWh/kg in 2020 to 63 kWh/kg in 2021.

The decrease of electricity consumption under the reduction process has been achieved by the efforts including the following:

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

It has been said that electricity consumption can be further reduced by additional process optimization and the economy of scale. It is assumed that it would contribute to the reduction of polysilicon prices. Besides the Siemens process, fluidized bed reactor (FBR) is used to produce polysilicon. The advantage of the process is a lower energy consumption and granular shaped products, which can be fully packed in the crucibles. In July 2022, GCL Technology in China started operations of two new FBR process plants in Jiangsu and Leshan with 30,000 tonnes/year and 100 000 tonnes/year capacity, respectively. According to GCL, the total electricity consumption of this process is 14,8 kWh/g and the quality meets the requirement for n-type sc-Si wafers.

In 2021, the USA decided to ban US imports of material from Chinese-based Hoshine Silicon Industry that produces metallic silicon, a base material of polysilicon,. With this measure, future production locations might change but for the time being, China is assumed to remain the global top producer of polysilicon. Then, in July 2021, the US administration established Uyghur Forced Labor Prevention Act (UFLPA) and started to enforce the ban on solar products made in Xinjian Uyghur. Because of this measure, new polysilicon plants are planned in Inner Mongolia and other regions outside of Xinjian Uyghur. The measure is expected to accelerate the traceability of the product's origins. It is also expected to trigger an increase of the US polysilicon production for the PV sector with the Biden administration's efforts to recover the US PV manufacturing.

INGOTS & WAFERS

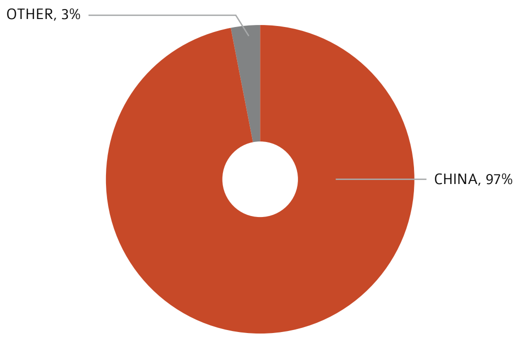
To produce sc-Si ingots or mc-Si ingots, the basic input material consists of highly purified polysilicon. The ingots need to be cut into bricks or blocks and then sawn into thin wafers. Conventional silicon ingots are of two types: sc-Si ingots and mc-Si ingots. The first type, although with different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

THE UPSTREAM PV SECTOR / CONTINUED

In addition to major ingot/wafer manufacturers, some PV cell/module manufacturers also partly manufacture silicon ingots and wafers for their own in-house use. Due to the cost pressure, some of these major PV module manufacturers that established vertically integrated manufacturing are shifting to procuring wafers from specialized manufacturers because of the cost and quality advantages.

The global wafer production amounted to 233 GW in 2021, a 39% increase from 2020. The production capacity of wafers as of the end of 2021 reached 415 GW/year from 218 GW/year in 2020. It is notable that production capacity and the volume for mc-Si wafers decreased while those of sc-Si wafers increased due to the demand for higher efficiency PV modules. As shown in Figure 4.3, China has more than 97% of the global production of wafers. In 2021, China produced 226,6 GW of wafers, a 40% year-on-year increase. Among them, around 22,6 GW of wafers are exported to other PV cell manufacturing countries such as Malaysia, Vietnam, Thailand, Korea, Taiwan and India.

FIGURE 4.3: SHARE OF PV WAFER PRODUCTION IN 2021



SOURCE IEA PVPS, RTS CORPORATION

In 2021, it was notable that the share of large-sized wafers increased. 158,75 to 166 mm sized wafers accounted for around 50% of the total production and the share of large-sized 182 (M10) to 210 (M12) mm wafers increased from 4,5% in 2020 to 45%. It is expected that the share of large-sized wafers will increase further and that they will become major products by 2030. A reduction of the wafer thickness was reported in 2021. In 2020, the thickness of 158,75 - 166 mm wafers were 175 to 180 μm. It decreased to 160 μm in 2021 due to the efforts to reduce polysilicon usage. The thickness of larger wafers in 2021 was 165 μm and is expected to be 155 μm in 2022.

In the first half of 2022, China manufactured 152,8 GW of wafers, a 45,5% increase of the previous year. In 2022, further increase of the share of larger-sized wafers is expected. Tungsten wires are used instead of diamond wires, in order to reduce the wafer thickness.

The spot price of c-Si wafers generally follows the price of polysilicon. In January 2021, the price of sc-Si wafer (158,75 mm/161,75 mm) was 0,34 USD/piece and increased to 0,74 USD/piece in November 2021. In July 2022, the reported price of the same size was 0,779 USD/piece. Lager wafers (182 mm) were priced at 0,969 USD/piece.

Outside of China, wafer manufacturing capacities were reported in Malaysia, Vietnam, Norway and Taiwan. New capacities were announced in several countries in 2021 and later. In India, Emmvee Photovoltaic Power is planning vertical production from wafers to PV modules. Companies such as CIL Solar PV are planning wafer production in India utilizing the government subsidy. Astrasun Solar in Hungary is planning to establish 1,8 GW/year line in a vertical production plant. French company, Carbon is planning to include wafer capacity in France. In Russia, Hevel Solar is planning 1,3 GW/year of production capacity as a part of HJT PV cell/ module production. Russian Unigreen Energy also worked on 1,3 GW/year production line of n-type ingots and wafers.

In Spain, Greenland Gigafactory announced a plan to establish a wafer production factory in Sevilla as part of a plan to establish vertically integrated PV fab. In Turkey, Kalyon Solar Technologies established a 500 MW/year PV manufacturing plant including the wafer process. In India, wafer manufacturing is planned by several companies as a part of PV manufacturing plans combined with the utility-scale projects rights. Chinese companies also plan to have wafer capacity production outside of China. For example, ET Solar is planning to build a 5 GW/year wafer plant in Vietnam. JinkoSolar announced a plan to build a 7 GW/year ingot/wafer plant in Vietnam in 2022.

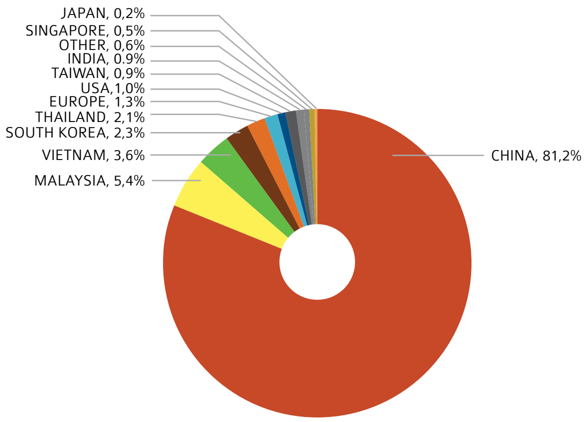
Startup companies in the USA and Europe are developing a kerfless manufacturing process to manufacture wafers without using conventional ingot growth or wire-sawing processes. CubicPV in the USA established by the merger of 1366 Technologies and Hunt Perovskite Technologies is planning to establish a 2-GW wafer manufacturing facility in India with the direct wafer process. Nexwafe (Germany) financed several million Euros for the commercialization of its Epiwafers technology to establish a 500 MW/year factory by 2024. Other companies working on new technologies include Leading Edge Crystal Technologies (USA) and Crystal Solar (USA).

SOLAR CELL AND MODULEPRODUCTION

Solar Cell Production

The global solar cell (c-Si and thin-film solar cell) production reached around 241 GW in 2021, a 35,4% increase from 2020 (178 GW). The global manufacturing capacity as of the end of 2021 is around 441 GW/year. As in the previous year, China was the world's largest producing country of solar cells. China produced around 198 GW of solar cells in 2021, a 46,8% increase from 135 GW in 2021. China's reported solar cell manufacturing capacity is 360 GW/year in the end of 2021. 160 GW/year have been added from 2020 onwards. As shown in Figure 4.4, China's solar cell production volume accounts for 82,2% of the total global production. As shown in Table 4.1, the top 5 solar cell manufacturers are Chinese companies.

FIGURE 4.4: SHARE OF PV CELL PRODUCTION IN 2021



SOURCE IEA PVPS, RTS CORPORATION

TABLE 4.1: GLOBAL TOP FIVE MANUFACTURERS IN TERMS OF PV CELL/MODULE PRODUCTION AND SHIPMENT VOLUME (2021)

RANK	SOLAR CELL PRODUCTION (GW)		PV MODULE PRODUCTION (GW)		PV MODULE SHIPMENT (GW)	
1	TONGWEI SOLAR	32,9	LONGI GREEN ENERGY TECHNOLOGY	38,9	LONGI GREEN ENERGY TECHNOLOGY	38,5
2	LONGI GREEN ENERGY TECHNOLOGY	29,6	TRINA SOLAR	26,2	JA SOLAR TECHNOLOGY	25,5
3	JA SOLAR TECHNOLOGY	21,2	JA SOLAR TECHNOLOGY	25,9	TRINA SOLAR	24,8
4	SHANGHAI AIKO SOLAR ENERGY	19,5	JINKOSOLAR	21,4	JINKOSOLAR	22,2
5	TRINA SOLAR	18,9	CANADIAN SOLAR	16,7	CANADIAN SOLAR	14,5

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

SOURCE RTS CORPORATION (WITH SOME ESTIMATES)

The countries besides China which have reported production of solar cells are Malaysia (13,1 GW), Vietnam (8,8 GW), Korea (5,5 GW), and Thailand (5 GW). Europe, USA, India and Japan also reported production. Figure 4.4 shows the production share of solar cell by country in 2021. Thailand and Vietnam are not subject to the safeguard tariffs by the USA and the production capacities are increasing in these countries. As of 2021, Malaysia had 18,6 GW/year of solar cell capacity. Vietnam and Thailand had 17 GW/year and 9,7 GW/year, respectively. In the USA, the solar cell production is mainly conducted by First Solar with their CdTe thin-film PV technology. As for c-Si solar cells, the demand for high efficiency solar cells has continued increasing. The share of sc-Si solar cells increased to 89% and the mc-Si share is around 7,7% in 2021. According to the ITRPV 2021 report, the share of PERC/PERT/PERL/TOPCon technologies reached around 85% from 76% in 2020. The BSF technology share decreased to less than 10%. The share of higher efficiency technologies such as Si-heterojunction (SHJ) and back contacts, including metal wrap through, remained around 5%. As in the previous years, investment in these technologies has been active throughout 2021. More than 20 companies are planning to produce and commercialize SHJ technologies. In China, the share of n-type Si high efficiency technologies in 2021 remains at 3%. It is expected to increase to 13% in 2020. As mentioned in the wafer section, the size of solar cells has become larger, adopting M10 or M12 wafers. In 2021, it is notable that the share of bifacial solar cells in the global market reached 50%. It is expected to reach more than 60% in 2022. One of the reasons of this growth is that bifacial products are exempted of the US safeguard duties. Also, the output increase with single axis tracker contributed to the market growth.

THE UPSTREAM PV SECTOR / CONTINUED

As for wafer prices, cell prices were also affected by the polysilicon price. In January 2021, the mono-PERC cell spot price was between 0,12 to 0,14 USD/W depending on the wafer size. The price level increased to 0,15 to 0,19 USD/W in November 2021. After that, the price changed according to the demand and as of July 2022, the price range is 0,155 to 0,18 USD/W.

In the first half of 2022, China produced 135,5 GW of c-Si solar cells, a 46,6% increase from the previous year (123,6 GW). Announcements of commercialization of n-type Si solar cell have been observed, these account for one third of announced production enhancements. In China, major utility companies conducted tenders using n-type technologies. The demand for n-type technologies was more than 4 GW.

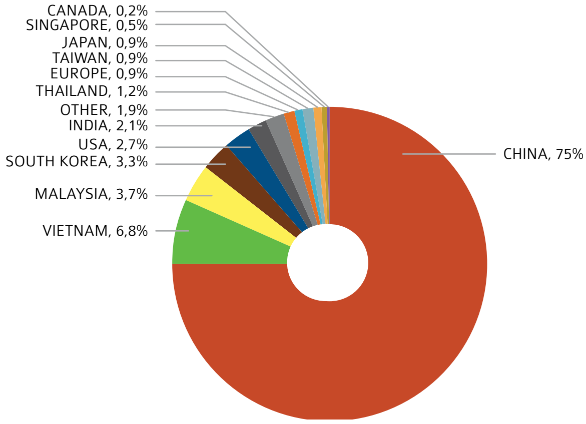
Among the materials used for solar cells, the price of silver soared in 2021. According to the Silver Institute, the silver price increased by around 22% in 2021. For this reason, solar cell manufactures are making efforts to reduce silver consumption in the electrodes. The replacement of silver by copper or aluminum is also being considered by manufacturers and suppliers.

SOLAR MODULE PRODUCTION

Global PV module production (c-Si PV module and thin-film PV module) showed an increase following the global demand for PV system installation from 178,5 GW in 2020 to 242 GW in 2021. As shown in Figure 4.5, as in 2020, China continued to be the largest producer of PV modules in the world. China produced 181,8 GW of PV modules in 2021 with 359 GW/year of production capacity. In 2021, the amount of exported PV modules from China achieved its highest record in history according to CPIA, Chinese PV Industry Association. About 98,5 GW of PV modules were shipped to overseas markets. As shown in Table 4.1, the top 5 PV module manufacturers are Chinese companies.

As in 2020, the second largest PV module producing country in 2021 was Vietnam with 16,4 GW, a 13,8% increase from the previous year (14,13 GW). Malaysia (9,1 GW) ranked third and Korea ranked fourth with 8 GW of PV module production. The USA ranked fifth with 6,6 GW of PV module production.

FIGURE 4.5: SHARE OF PV MODULE PRODUCTION IN 2021



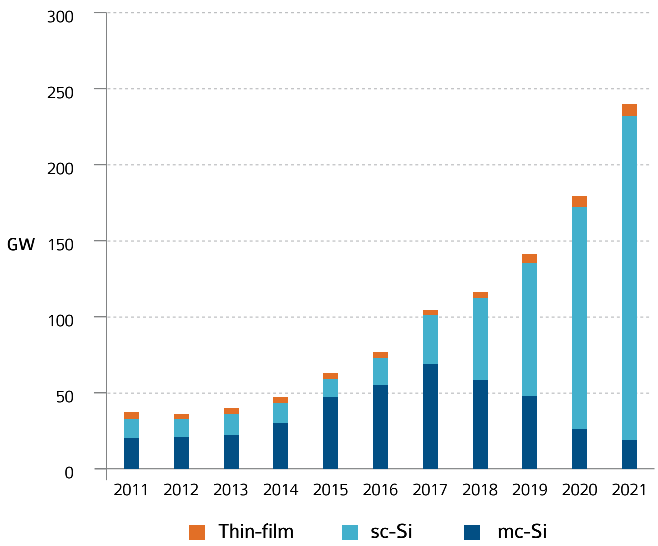
SOURCE IEA PVPS, RTS CORPORATION

In case of the USA, its policy to guard domestic manufacturers with import duties, PV module production capacity has been increasing and it is expected that its production will increase as President Biden announced to increase the US production capacity to 22,5 GW/year by 2024 and incentives for production will be implemented under the Inflation Reduction Act enforced in August 2022. Local production of PV modules is being promoted in India and Europe as well. It is expected that higher logistic costs and the demand for a lower carbon footprint, the economic stimulation and the risk mitigation depending on specific production locations will diversify the manufacturing sites in the coming years.

The PV module prices also kept higher levels in 2021, mainly due to the higher polysilicon prices. In January 2021, the average spot price of a typical sc-Si PV module was 19,2 USD cents/W. It increased to 26 USD cents/W in October 2021. By the end of December 2021, it dropped to 24,7 USD cents/W. In July 2022, the price level remained high at 25,6 USD cents/W. Besides polysilicon, glass and polymer materials also had impacts on the PV module prices. According to a statement issued in September 2021 by the five major Chinese PV module manufacturers (LONGi Green Energy Technology, JinkoSolar, and Trina Solar, JA Solar Technology and Risen Energy), the price of glass for PV modules increased by 18,2% from August 2021 and the EVA price soared 35% in August in 2021. The tight supply caused by higher demand and electricity consumption control, resulted in the prices of these components showing a rise and fluctuations. It is expected that the expansion of the manufacturing capacity of these materials will stabilize the prices and the replacement of EVA to polyolefin will be advanced.

SOLAR MODULE TECHNOLOGY

FIGURE 4.6: PV MODULE PRODUCTION PER TECHNOLOGY IN IEA PVPS COUNTRIES IN 2021



SOURCE IEA PVPS, RTS CORPORATION

In 2021, as shown in Figure 4.6, the share of c-Si PV module was 96,6%, a slight increase from 96,4% in the previous year. Among c-Si technologies, sc-Si increased its share from 81,9% to 88,9% in 2021. As mentioned in the section on wafers and cells, the adoption of larger-sized solar cells increased. PV modules adopting half-cut c-Si solar cells have more than 80% share of the total in 2021. The shingled PV module technology (overlapping the edges of solar cells without ribbons) and the seamless soldering technology were also adopted.

Thin-film silicon technologies slightly lost their share from 3,6% to 3,4%. About 8,2 GW of thin-film PV modules were produced in 2021. Among them, 7,9 GW were CdTe PV modules produced by First Solar (**USA**). Other thin-film technologies produced in 2021 were CIGS with less than 500 MW and amorphous-silicon PV modules. In 2021, Solar Frontier, a Japanese CIS thin-film PV module manufacturer decided to withdraw from manufacturing in order to shift to the PV system installation business utilizing c-Si technologies. Thin-film PV modules were mainly produced in **Malaysia**, **USA**, **Japan**, **Germany**, and **China**. In many of the IEA PVPS member countries, R&D and commercialization efforts on CIGS thin-film PV modules focus on the improvement of conversion efficiency and throughput as well as the enlargement of module size. Application for a tandem solar cell using c-silicon and perovskite technologies is also studied. The share of thin-film PV modules in this segment is expected to grow for specific applications for curved surfaces, windows, or skylights with light transmitting functions, applications requiring lightweight modules.

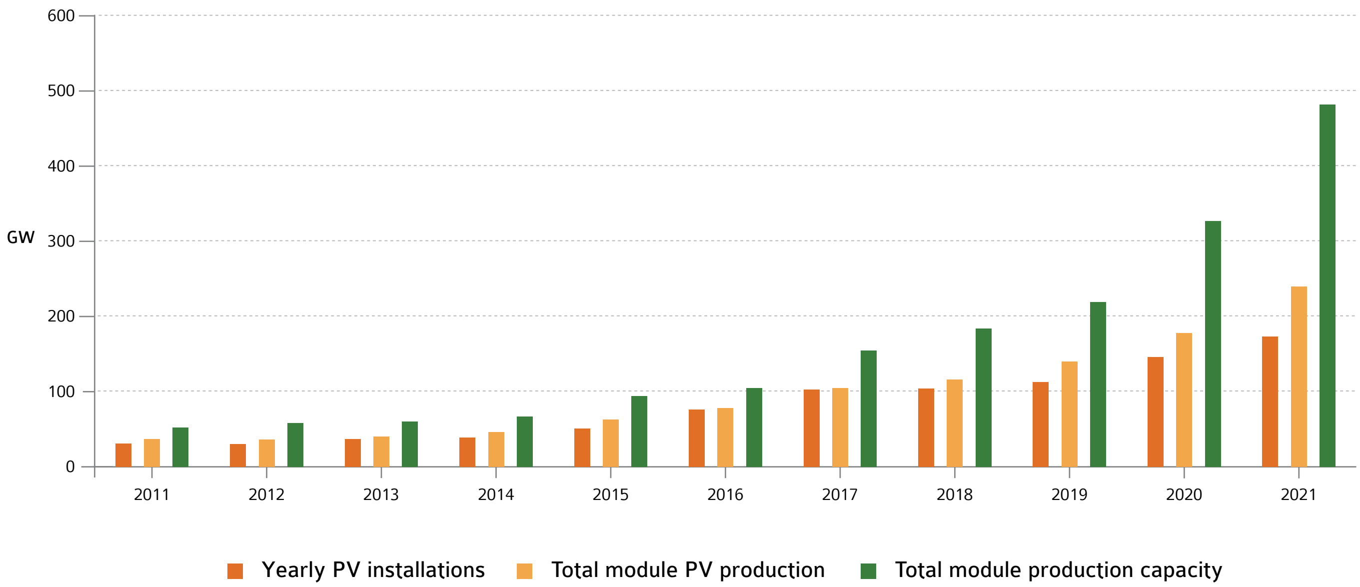
High-efficiency multi-junction PV cells/modules have been produced, mainly using III-V materials for space applications. R&D activities for high-efficiency multi-junction (MJ) PV have been active in the **USA**, Europe and **Japan**. R&D for tandem solar cells using c-Si and MJ cells is also continued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

Following the rapid improvement of conversion efficiency in a short time, efforts on the commercialization of PV cells/modules were reported in 2021 and 2022. In **China**, several companies are working on commercialization. Hangzhou Microquanta Semiconductor announced that it shipped 5 000 pieces of perovskite PV modules in July 2022. Shenzhen Infinite Solar Energy Technology successfully secured financing, targeting to establish a pilot production line in 2022. GCL Optoelectronics announced it installed perovskite PV modules in the facilities used for the Winter Olympic games in 2022. In addition to these Chinese companies, Wonder Solar started to establish a 200 MW/year pilot line aiming at developing a 1 GW factory in 2022. Outside of **China**, Saule Technologies (**Poland**) completed a manufacturing facility for flexible perovskite solar cells in May 2021. In the **UK**, PowerRoll started a roll-to-roll pilot production line in February 2022. In the **USA**, Swift Solar is working on flexible PV modules.

Commercialization of tandem technologies using perovskite and c-Si solar cell is also globally active. Oxford PV in the **UK** completed a 100 MW/year production line for perovskite/ c-Si tandem PV in July 2021. While announcements of efforts have been reported, it remains to be seen if perovskite technology could replace some of the market shares of conventional c-Si or thin-film PV module technologies.

THE UPSTREAM PV SECTOR / CONTINUED

FIGURE 4.7: YEARLY PV INSTALLATION, MODULE PV PRODUCTION AND MODULE PRODUCTION CAPACITY 2011-2021 (GWp)



NOTE: REVISED BASED ON CPIA DATA AND RTS SURVEY

SOURCE IEA PVPS, RTS CORPORATION

PRODUCTION CAPACITY EVOLUTION

Figure 4.7 and Table 4.2 show the evolution of global annual installed capacity, PV module production amount and PV module production capacity. In 2021, the production capacity increased from 327 GW/year in 2020 to 483 GW/year in 2021. It should be noted that 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 at the level of about 380 GW/year in 2021. The speed of capacity enhancement is faster than the market development so the price level of PV modules is expected to be stabilized if the supply for polysilicon eased in the coming years.

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

ACTUAL PRODUCTION				PRODUCTION CAPACITIES			
YEAR	IEA PVPS COUNTRIES	OTHER COUNTRIES	TOTAL	YEAR	IEA PVPS COUNTRIES	OTHER COUNTRIES	TOTAL
1993	52		52	80		80	65%
1994	0		0	0		0	0%
1995	56		56	100		100	56%
1996	0		0	0		0	0%
1997	100		100	200		200	50%
1998	126		126	250		250	50%
1999	169		169	350		350	48%
2000	238		238	400		400	60%
2001	319		319	525		525	61%
2002	482		482	750		750	64%
2003	667		667	950		950	70%
2004	1 160		1 160	1 600		1 600	73%
2005	1 532		1 532	2 500		2 500	61%
2006	2 068		2 068	2 900		2 900	71%
2007	3 778	200	3 978	7 200	500	7 700	52%
2008	6 600	450	7 050	11 700	1 000	12 700	56%
2009	10 511	750	11 261	18 300	2 000	20 300	55%
2010	19 700	1 700	21 400	31 500	3 300	34 800	61%
2011	34 000	2 600	36 600	48 000	4 000	52 000	70%
2012	33 787	2 700	36 487	53 000	5 000	58 000	63%
2013	37 399	2 470	39 869	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%

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 8 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. 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 domestic or regional manufacturers tended to dominate domestic or regional PV markets. However, with the growth of the Chinese market, the dominance of Chinese products has been visible in both utility-scale and distributed PV markets. According to CPIA and other sources, the total production of inverters in China was about 155 GWac, a 55% increase from the previous year (100 GWac), excluding OEM production for the companies headquartered outside of China. CPIA also reported that 63GWac of inverters were exported. China's share in inverter shipments is estimated to be around 72% in 2021, a slight year-on-year increase.

Generally, inverters are categorized into three types: central inverters, string inverters, and micro-inverters called "MLPE, module-level power electronics". In 2021, the share of central inverters used for large-scale utility or industrial applications is about 34% and the market share of string inverters used for residential and small to medium-scale commercial PV systems is 64%. The share of MLPEs remains low, about 1% mainly used for residential and small-scale commercial applications. Recently, the size of inverters increased due to the pressure for LCOE reduction. The largest central inverter capacity is 5 MW and the maximum capacity of string inverters increased to 350 kW level. An improvement in inverter efficiency has been observed and recent products have 98% efficiency and higher. Larger-sized PV modules using larger-sized solar cells have also driven technology improvement of inverters, as they are required to synchronize higher-watt peak PV modules. Inverters need to meet higher currents from PV modules, which increased from 9 A to 11 A to 11,5 A. In the case of PV modules using 210 mm solar cells, 17 A of electrical current is generated. Advanced semiconductors (SiC or GaN) contribute to these improvements and have achieved compact designs with lighter weight, allowing 1500 V maximum DC string voltage. It should be noted that the global supply gap of semiconductors also resulted in delays of inverter shipments or a reduction of production. This situation should be eased with the enhancement of the semiconductor manufacturing capacity in the coming years.

The inverter technology has become more and more important since it is increasingly considered as the core of the PV system, supporting grid stability with new grid codes. New grid codes require the active contribution of PV inverters to ensure grid management and grid protection, new inverters with sophisticated control and interactive communications features with digital technologies are currently under development. With the growth of the self-consumption market, functions are equipped to optimize self-consumption with an energy management solution combining storage batteries and EVs with smart monitoring. Application of AI and machine learning for failure detection or optimization of electricity generation contributed to lowering the cost of O&M. In addition, inverter manufacturers entered the O&M business and the repowering business where aging PV power plants exist, mainly in Europe.

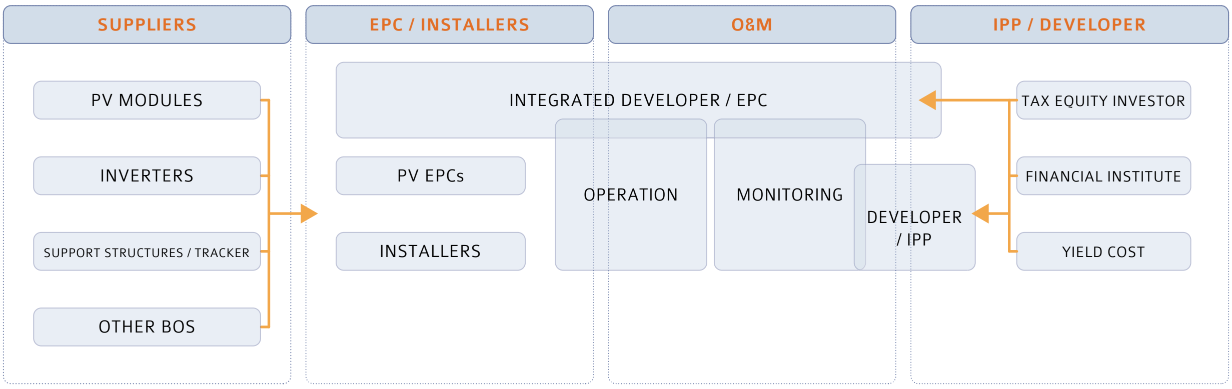
In addition to the conventional inverters mentioned above, the market of MLPE is growing in specific markets. Microinverters and DC optimizers (working at module level) are mainly adopted in the US residential market due to rapid shutdown requirements imposed by the National Electricity Code (NEC). MLPE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

Among other BOS segments, the market of single-axis trackers has been growing. The market size of 2021 reached around 55GW, a 21% increase from 2020. The largest tracker market is the USA, where the majority of utility projects are built with single-axis trackers. The market for PV trackers is expanding to China, India, Brazil, Mexico, Chile, Argentina, South Africa, Saudi Arabia and the United Arab Emirates. In 2021, the price rise of steel was reported to affect the price and delays of the shipments. Besides utility-scale applications, trackers used for agriPV projects are developed and commercialized with a specific design to share solar energy with agricultural crops.

THE DOWNSTREAM PV SECTOR

In the PV industry, an overview of the downstream sector can be described as 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 developers sell PV power plants to Independent Power Producers (IPPs) or investors, some developers own PV power plants as their own assets. The companies providing Engineering, Procurement and Construction for PV systems (mainly utility-scale applications but larger commercial or industrial applications also fall into this category) are called EPCs. EPCs include pure-players companies and general construction companies offering services for installing PV systems. Integrated PV developers sometimes conduct at the same time EPC, operation and maintenance (O&M) services by themselves. Some companies develop PV power plants and own them, while others provide EPC and own PV power plants as well until they 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 the PV project development as equity or loan providers.

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



SOURCE IEA PVPS & OTHERS.

Companies doing business in the downstream sector have various origins: subsidiaries of electric utilities, subsidiaries of PV module or polysilicon 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 the business deployment in emerging 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 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, Canadian Solar, and Hanwha Solutions (Korea) are also active in the downstream sector. Notable polysilicon manufacturers investing in the international downstream business are GCL-Poly Energy and OCI.

Oil and other major energy companies also entered into the renewable energy market. Especially, European companies are active in this field. For example, BP (UK) is shifting to an integrated oil company (IOC) to an integrated energy company (IEC). Total (France) is focusing on gas and low carbon electricity and develops PV projects globally. Shell (UK/Netherlands) announced to set out its strategy to accelerate its transformation into a provider of net-zero emissions energy products and services. In 2021, investments in renewable energy companies, setting up JVs and acquisition of renewable energy business of these companies were frequently reported.

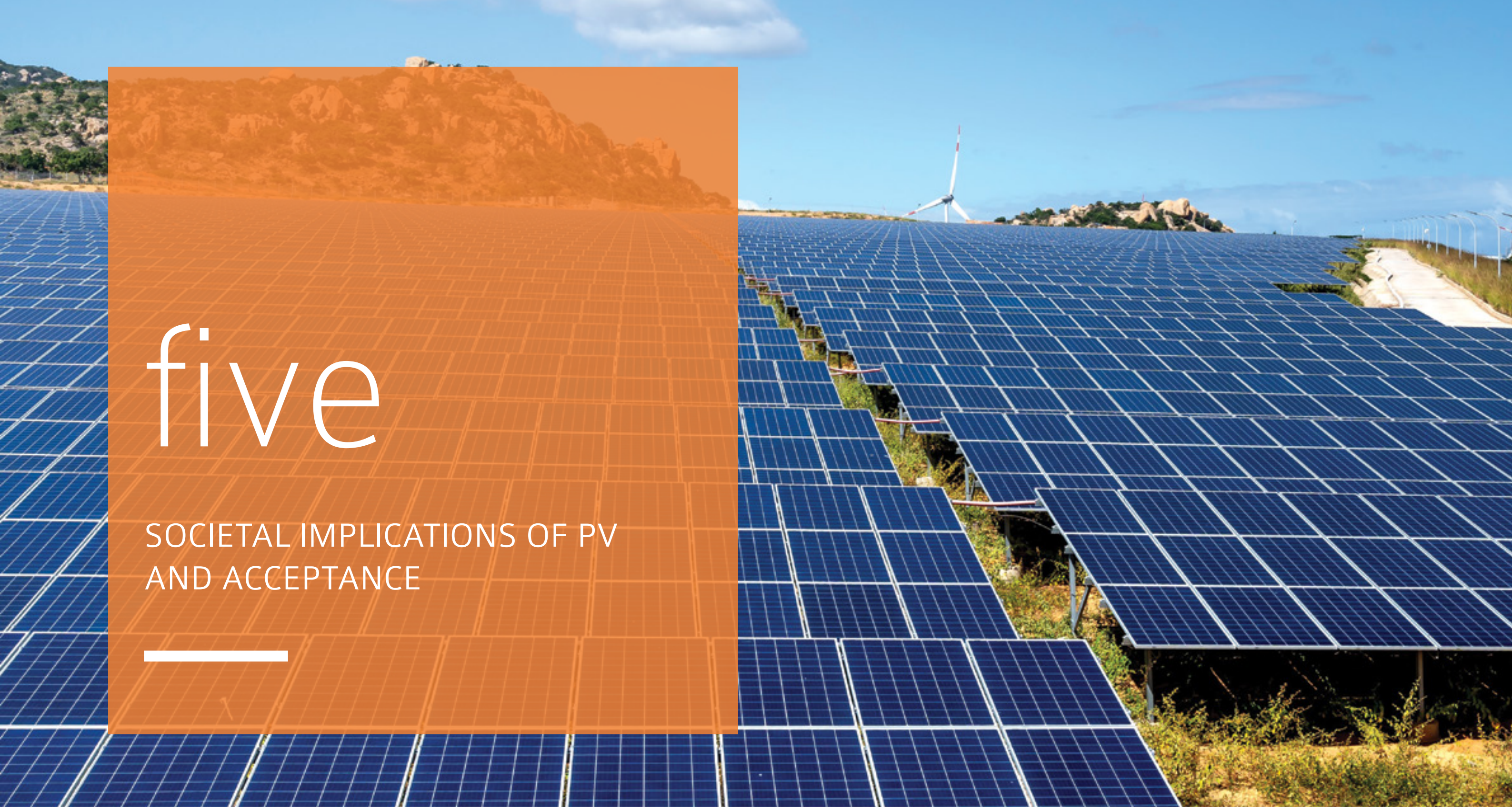
THE DOWNSTREAM PV SECTOR / CONTINUED

In the downstream sectors, business models have been changing with the demand for renewable electricity from users seeking to procure 100% renewable power for their business operations. Especially in countries where the electricity market is liberalized, PV electricity is sold directly to the company users by IPPs These cases are called Corporate PPA (CPPA). BNEF reported that the total volume of global CPPA signed in 2021 reached 31.1 GW increased by 24% from 25.1 GW in 2020. According to BNEF analysis, most of the projects were PV generation, and almost one-third of the total, 20,3 GW was contracted in the Americas. European PV markets are also growing, and a historic record of 8,7 GW was contracted. As previously mentioned, because of the price increase of PV modules and other components, LCOE of PV projects is expected to increase. However, energy prices based on fossil fuels are also rising, especially after the Russian invasion of Ukraine. As long as the gap exists, business cases of CPPAs are expected to grow more and more in diverse locations.

PV plus storage batteries projects are announced under auctions and other mechanisms in the USA, Australia, Europe, Africa, Chile, India, etc. Various green hydrogen projects using PV power were also announced in 2021. Various countries have established hydrogen society roadmaps and have started green hydrogen projects. Green hydrogen is expected to play an important role in the energy transition and in R&D. Development for cost reduction has been promoted.

In distributed PV systems segment for residential, commercial and industrial applications, the demand for self-consumption and resilience is increasing.

In addition to these, obligations to install PV for new houses or buildings are being adopted at national and regional levels. These mandatory measures and tighter energy efficiency codes will drive the distributed PV market. In countries with an established PV market, where the distributed market was established such as the USA, Australia, Japan, Germany and other European countries, the demand for distributed storage batteries is increasing. Subsidies for storage batteries are available in some countries. PPA models are used to introduce PV systems into residential, commercial or industry facilities. It should be noted that the fast development of EVs might change the landscape of distributed PV systems as local storage batteries.



five

SOCIETAL IMPLICATIONS OF PV AND ACCEPTANCE

The PV sector has significant implications for the economy, for the society and for the environment. The positive impacts generated in these three areas show that PV is a main contributor on the path towards sustainability.

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 impact on the environment and the social aspects related to the development of PV are becoming essential. This chapter aims at providing key elements that can be used to promote a larger acceptance of PV development, while highlighting essential aspects.

Social acceptance is becoming a key topic when it comes to PV development in a certain number of countries around the world. Particularly, in countries with a historically predominant distributed PV market, where ground-mounted PV needs to develop in order to achieve renewable energy targets or in countries experiencing a market boom, the question of social acceptance is becoming central. The question of acceptance and its associated challenges is not limited to ground-mounted PV systems, even if these later concentrate the most resistance.

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 case of PV, in contrast to other renewable sources and especially wind, the initial acceptance of PV was positive. Most countries started by developing small-scale PV installations, mostly on roofs, and until 2006-2007, the general perception of PV was positive as its impact was marginal.

The first major drawback came from the massive start in Spain in 2007-2008 when the local feed-in tariff was so popular that PV developed fast, to the extent it had to be stopped by authorities, in fear of economic and budget consequences for the country. All 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 brake at 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. All subjects were used massively by PV opponents to reduce dramatically the social acceptance of PV. This

ACCEPTANCE OF PV DEPLOYMENT / CONTINUED

happened in Spain, France, Belgium, Czech Republic, Greece, Bulgaria, Romania to mention a few. These are European countries and the EU was the epicentre of PV development until 2011-2012. While the PV community forgot somehow the need for social acceptance, the reaction from policymakers was disproportionate and halted often almost completely the PV dynamics. In some countries like Belgium for instance, PV still suffers from a poor image and frightens policymakers.

Moreover, images of damage inflicted to PV systems by, for example typhoons in Japan, but also fire outbreaks, can deteriorate the acceptance of PV conveying the idea of poor reliability and a vulnerable technology.

In the last years acceptance has gradually increased, and the inherent competitiveness of PV contributed to increase the general acceptance.

SOCIO-POLITICAL AND COMMUNITY ACCEPTANCE

It can be differentiated 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 politicians, policy makers, key stakeholders and the public. It involves considerations about the legal and regulatory framework. It resonates with concerns related to jobs, industry and local content. In multiple countries (Turkey, 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 introduced in tenders. 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 industrial decline for example.

Community acceptance is related to the acceptance by local stakeholders. It includes concerns over distributional justice (costs and benefits), procedural justice, and trust; where the 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. In general, the target is to overcome ignorance and misconception (e.g., about the land that is actually needed to meet the targets).

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 the acceptance and accelerate the deployment. For example in countries like France, individual self-consumption is gaining momentum these two last years, indeed consumers are becoming prosumers wich improves solar PV image. Such is the case for energy communities and the Community Solar initiative in the USA, which allow the fight against poverty and energy precariourness.

Such involvement can be seen under various angles:

- Prosumers are consumers producing part or all of their electricity with PV while maintaining grid connection. Prosumers policies, especially self-consumption ones are described in chapter 3.
- Energy communities, and the specific case of solar communities are involving communities in producing and managing energy, allowing a higher involvement of stakeholders.
- Energy access is emerging countries has shown for a long time that the implication of the populations significantly increases the adoption of decentralized energy sources.
- Companies and especially utilities involved in the PV business are known to become advocates of the energy transition.

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 main solutions for reducing our greenhouse gas emissions.

The energy sector is responsible for a major part of the global CO_2 emissions, with energy-related emissions evaluated at 33 Gt CO_{2eq} in 2021.[1]

Increasing the PV share in the grid mix can significantly reduce the emissions from power generation. The global average carbon intensity of electricity was around 475 g CO_2/kWh in 2019 whereas for 1 kWh produced by PV the emitted CO_2, considered 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 CO_2 emissions that are avoided by PV on a yearly basis can be calculated considering the amounts of electricity that can be produced annually by the cumulated PV capacities installed at the end of 2020 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 CO_2 emission factors (g CO_2/kWh) of both PV electricity and grid mix electricity are taken from the IEA PVPS Task 12 databases.

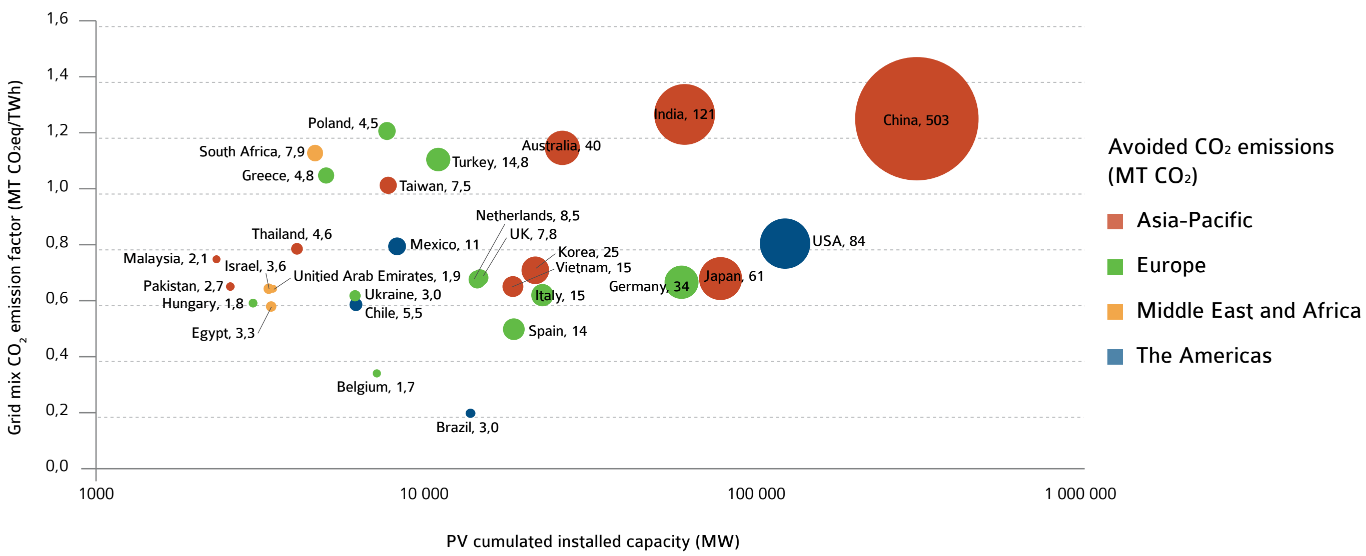
CO_2 avoided

1 060 MT $CO_{2,eq}$

Using this methodology, calculations show that the PV installed capacity today avoids up to 1060 million tonnes of CO_{2eq} annually. Thus, it avoids more than 3% 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.

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

FIGURE 5.1: CO_2 EMISSIONS AVOIDED BY PV [MT $CO_{2,EQ}$]



FOOTNOTES

1 www.iea.org/reports/global-energy-review-2021/co2-emissions

CLIMATE CHANGE MITIGATION / CONTINUED

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

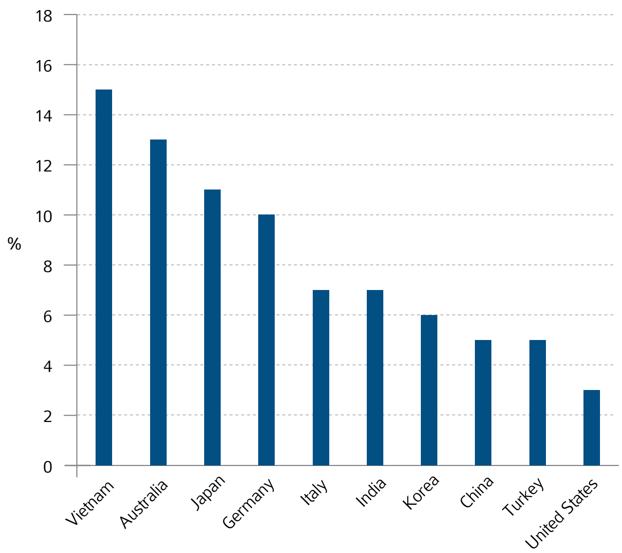
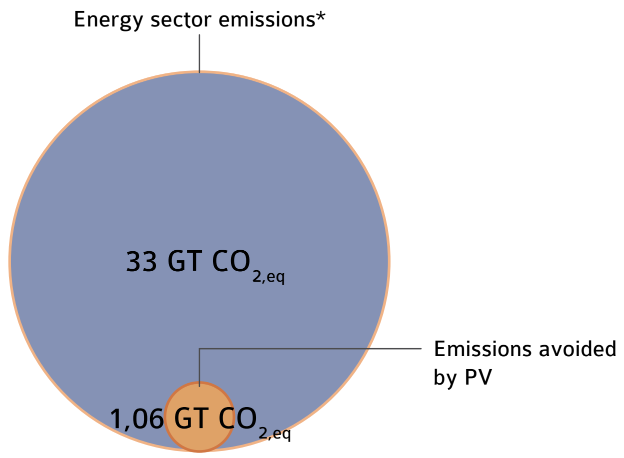


FIGURE 5.2B: AVOIDED CO_2 EMISSIONS AS PERCENTAGE OF ENERGY SECTOR TOTAL EMISSIONS



*Energy related CO_2 emissions from fuel combustion

SOURCE IEA PVPS & OTHERS

VALUE FOR THE ECONOMY

The turnover of the PV sector in 2021 amounted to around 190 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 Operation & 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 8,1 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 10 Billion USD per year, if all operations could be included.

Turnover PV

190 Billion USD

Global business value

+ 19% in 2021

O&M

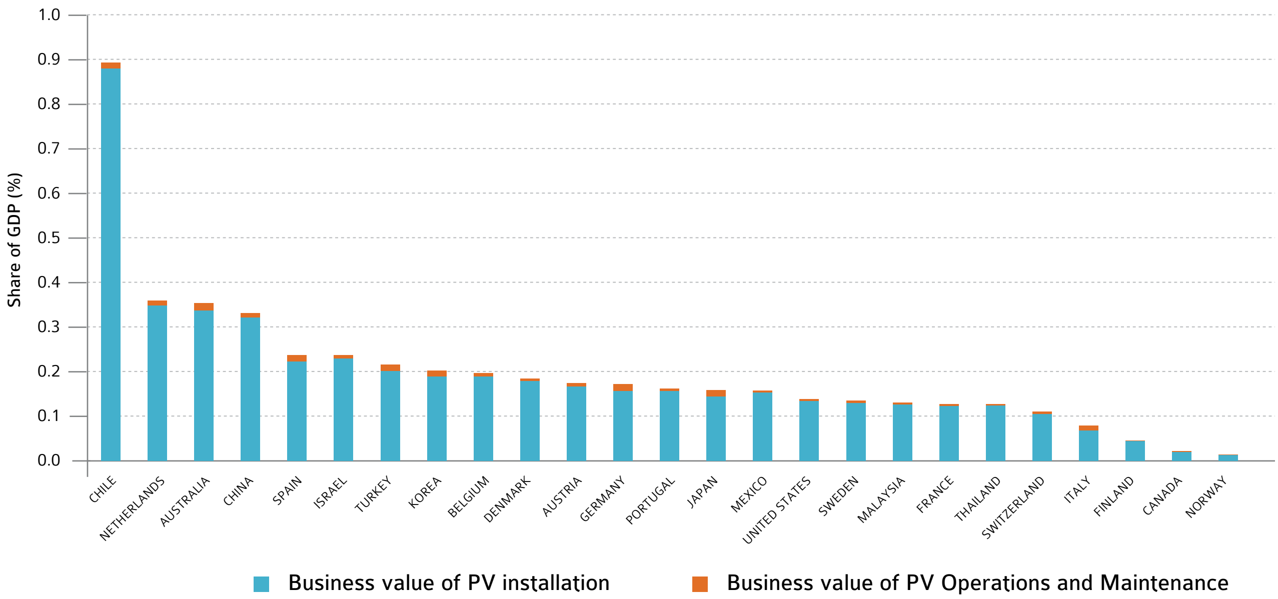
8,1 Billion USD

Compared to last year and in parallel to the growth of the annual market, the global business value of PV installations has increased by around 30% and so did the global value for O&M as well according to our estimates. This part of the PV economy is bound to grow further, powered by 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 decentralized production and the existence of transnational companies. However, a specific approximation of the industrial business value of PV was performed for IEA PVPS major PV manufacturing countries and is presented in a specific section below.

CONTRIBUTION TO THE GDP

FIGURE 5.3: BUSINESS VALUE OF THE PV MARKET IN 2021



SOURCE IEA PVPS & OTHERS

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 represented less than 0,4% in almost all considered countries (with the exception of Chile for which this share amounts to 0,9%) and more than 0,05% in most of them, a range very similar to last year. On a global scale, PV business value represents around 0,2% of the GDP compared to around 2,3% for energy investments.

On a general perspective, the numbers presented as a share of GDP show that the investment in the energy transition, even if these numbers would be multiplied by a factor of 10, would stay in a reasonable range and would not significantly change the availability of financial resources.

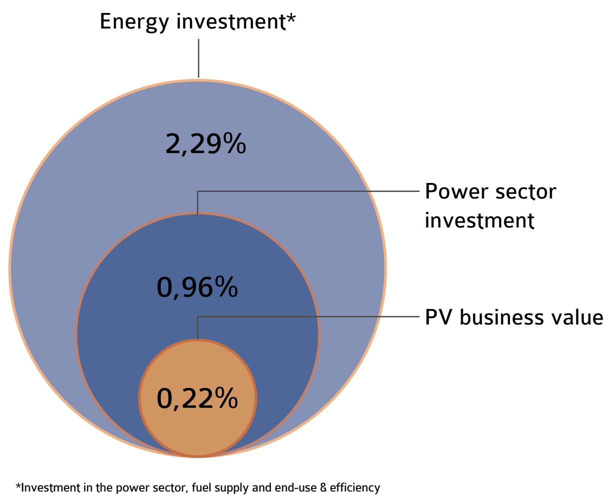
VALUE FOR THE ECONOMY / CONTINUED

TABLE 5.1: TOP 10 RANKING OF PV BUSINESS VALUES

RANK	COUNTRY	BILLION US$
1	CHINA	42
2	UNITED STATES	29
3	JAPAN	8
4	GERMANY	7,3
5	AUSTRALIA	5,5
6	SPAIN	4,7
7	FRANCE	3,9
8	NETHERLANDS	3,7
9	KOREA	3,5
10	CHILE	2,8

SOURCE IEA PVPS & OTHERS

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



SOURCE IEA PVPS & OTHERS

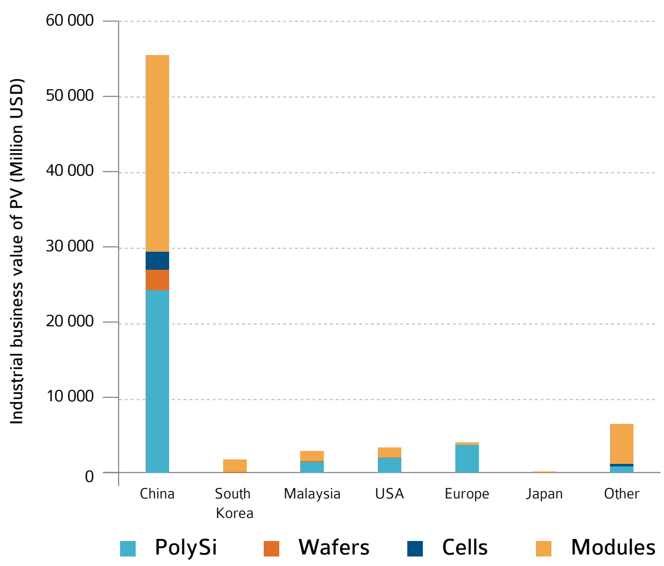
INDUSTRIAL VALUE OF PV

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 approximated 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 take into account are based on average prices reported by member countries. We consider that equipment and materials are included in this computed value. BoS, including inverters are not considered here.

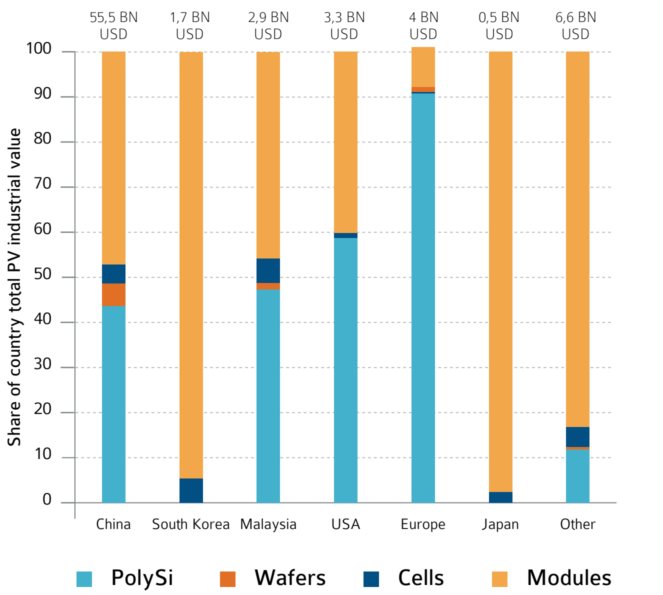
The estimated global industrial value of PV established itself around 74 Billion USD in 2021 Figure 5.5 A, 5.5 B, 5.5C show for IEA PVPS major PV manufacturing countries the estimated contribution of each step of the value chain in the PV industrial value for each country in absolute and relative terms as well as the comparison of this value to their GDP.

FIGURE 5.5A: ABSOLUTE PV INDUSTRIAL BUSINESS VALUE IN 2021



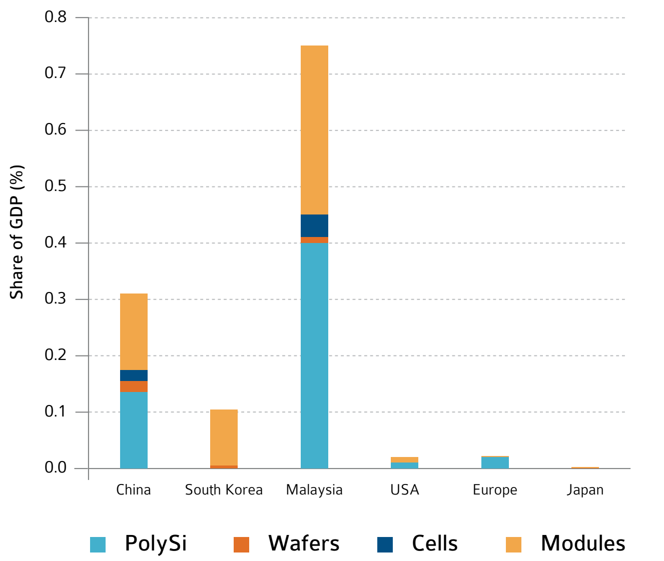
SOURCE IEA PVPS & OTHERS

FIGURE 5.5B: PV INDUSTRIAL BUSINESS VALUE ALONG THE VALUE CHAIN IN 2021



SOURCE IEA PVPS & OTHERS

FIGURE 5.5C: PV INDUSTRIAL BUSINESS VALUE AS SHARE OF GDP IN 2021



SOURCE IEA PVPS & OTHERS

China is by far the predominant manufacturing country in all steps of the PV value chain, shows an approximate share of 0,3% of its GDP represented by the PV Industry (polysilicon, wafers, cells and modules). Remarkably, while having much lower production volumes, the PV industry in **Malaysia** represents a significantly higher share of the country's GDP compared to **China**, exceeding 0,7%. **Korea** shows an approximate 0,1% share, while remaining countries do not exceed 0,03%.

For the BoS, the industry is significantly more distributed, and production occurs in many countries. It is not counted as such here, but such an analysis would make sense to grasp the extent of the PV industry impact on the countries' economic landscape.

SOCIAL IMPACTS EMPLOYMENT IN PV

Figure 5.4 gives an overview of the total 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 4,3 million people globally at the end of 2021. An estimated 1,2 million were employed in the upstream part, including materials and equipment, while 3,1 million were active in the downstream part, including O&M.

VALUE FOR THE ECONOMY / CONTINUED

PV sector employed an estimated

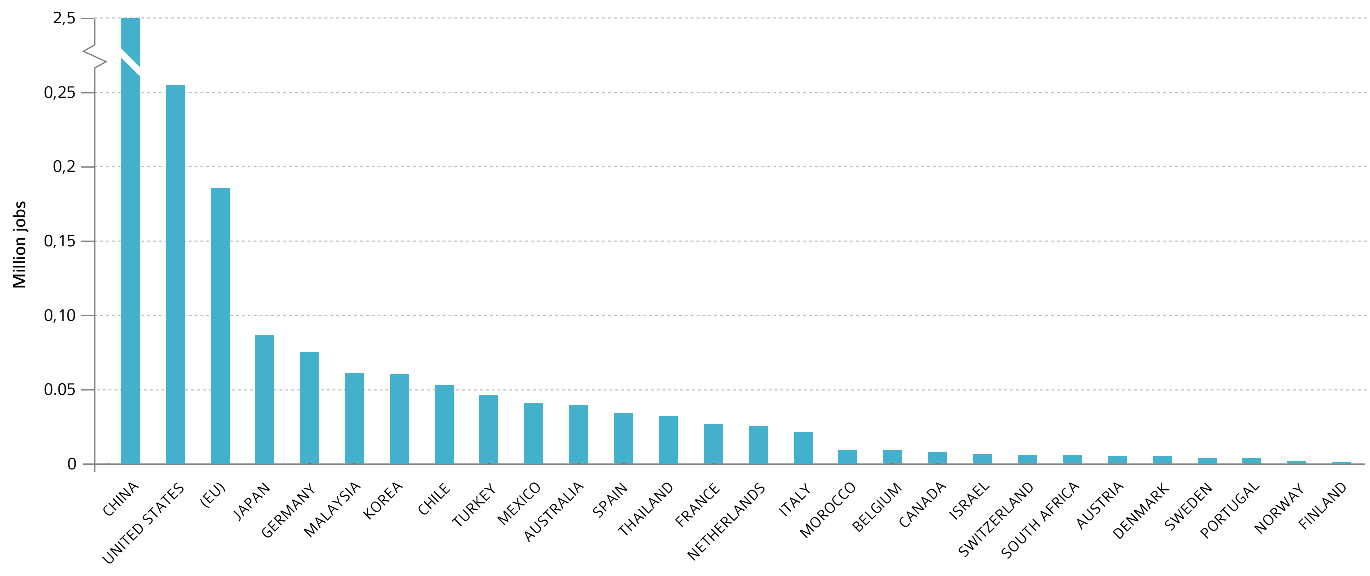
4,3 million people in 2021

As the leading producer of PV products and the world's largest installation market, **China** is markedly leading PV employment with around 2,5 million jobs in 2021, which corresponds to a significantly higher job intensity than almost anywhere else. Lower by one order of magnitude, the **USA** shows a total PV employment of about 255 000 FTE. The **European Union** comes third in the ranking of IEA PVPS countries with about 185 000 jobs, followed by **Japan** which takes fourth place with 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.

When specifically focusing on the development and installation activities, which are more labour intensive than manufacturing, it can be observed that the average FTE intensity per installed MW is around 15. 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.

FIGURE 5.6: GLOBAL EMPLOYMENT IN PV PER COUNTRY



SOURCE IEA PVPS & OTHERS

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 4,3 million jobs in the solar PV sector worldwide in 2021, PV employs around one third of the total renewable energy workforce and remains number one in the employment ranking of the global renewable energy sector.

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 IEA PVPS member countries only, several countries have pushed through different schemes for local manufacturing in recent years, namely Canada, France, Morocco, Turkey and the USA. Other countries have succeeded in bringing many manufacturers to produce PV components in their country, such as Malaysia, which is the most successful example to date. Others, such as Chile and South Africa, are eyeing possibilities. With the disruptions in the PV value chain caused by the pandemics and the increases cost of shipment, the question of local manufacturing has gained traction in 2021 and 2022. 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 or Saudi Arabia, to name a few, are pushing hard to develop a local industry and increase their partial independence.

IMPACT ON ELECTRICITY BILLS

While many focused for years on the increase of electricity bills due to the incentives that were spent to develop PV (see chapter 3), few mention the merit-order effect. Numerous studies in various countries have shown that PV reduces wholesale market prices for electricity at the time of production. 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 compute but most studies conclude on significant savings and additionally, cost decrease in the distribution grid up to a certain penetration of PV. The argument that PV (and wind) might require additional gas peakers or coal-fired power plants is a wrong understanding of the dynamics of the balance between supply and demand of electricity. However, much remains to be done to explain carefully the advantages of PV in reducing the energy cost of end-consumers, even those without PV plants, and counter the false 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 contribution 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. Several examples can be highlighted.

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 would deserve a significant attention for electrification.

In China, since the end of 2015, 100% electrification of the country has been reached. So, there are no government supported projects for off-grid rural electrification anymore since 2016. However, a massive program for poverty alleviation leaning on PV was launched. It aimed to enhance the life standards of around 2 million households, especially in the most impoverished parts of eastern China by installing around 5 kW of PV per household. This policy was halted in 2021.

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 2016 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 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 Korea to reduce the electricity bill burden during the summer.

VALUE FOR THE ECONOMY / CONTINUED

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 make them 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. After this project, some other municipalities and/or some Regions are planning and carrying out similar initiatives.

In Australia, a number of measures were announced by State Governments in 2020 and have been maintained in 2021 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 M EUR budget in 2021), electric vehicle charging points or grid-connection financing.

In general, the low cost of PV electricity could reach more households to alleviate poverty, both in developed and developing countries. It 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, increasing electricity prices, the reality of PV in 2021 is that it represents a tremendous opportunity to reduce energy prices for the poorest citizens, as well as to reduce energy costs for social housing, public buildings, from schools to retirement homes, and increase the access to electricity for everyone. The energy crisis of 2022 has increased the competitiveness of PV to the extent that it could reduce the electricity bill of families and companies, with or without a suitable roof, using smartly the possibilities offered by delocalized (or virtual) self-consumption.

AESTHETICS AND LANDSCAPE

As the large-scale integration of photovoltaics into our energy system is necessary for achieving the energy transition, large areas of photovoltaic modules will become part of our landscapes. Very often landscape preservation issues are already a barrier to the implementation of the large-scale implementation of photovoltaics, as the social acceptance of such landscape transformation 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 the landscape design, paving the way to the design of sustainable, beautiful photovoltaic landscapes is not optionable 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, the so called "agrivoltaics" offer a solution to addressing concerns about energy vs. agricultural land use, as they maximize the 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.

Photo by Werner Slocum, NREL 65320

SIX

COMPETITIVENESS OF PV ELECTRICITY IN 2021

The rapid price decline that PV experienced in the last years has already opened possibilities to develop PV systems in many locations with limited or no financial incentives. However, the road to full competitiveness of PV systems with conventional electricity sources 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 competitiveness without any regulatory or financial support. There are also further barriers, other than economic, for PV to become the obvious alternative to coal (rather than gas) for utilities. Currently, many already unprofitable coal power plants are still in operation because the regulatory and financial structure is not tailored for so many coal units to become stranded assets.

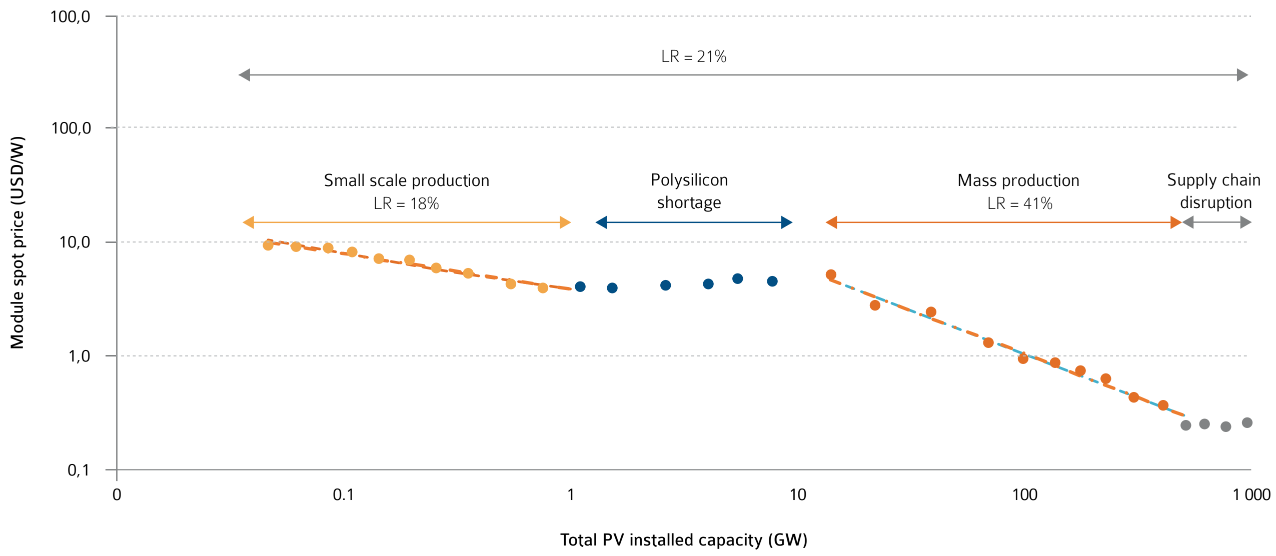
In addition, the choice of alternatives to coal is frequently not motivated by pure economics but is biased towards an electricity price and market design that favour gas-fuelled electricity. Since all sources of electricity have benefited at some point from such support, the question of the competitiveness of PV should be considered carefully. Hereunder, we will look at the key elements driving the competitiveness of PV solutions.

MODULE PRICES

The very first period of PV market development can be considered starting from the first prototypes to small scale production leading to a total PV installed capacity of around 2 GW. During this first phase, prices 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 is still the case today, beginning with the mass production of PV, especially in China. During this period ranging from 10 GW to current levels, significant economies of scale led to an impressive 41% learning rate over the last decade. Figure 6.2 illustrates the prices range for PV modules: it shows that prices globally stabilized in 2020 and increased slightly in 2021 under the impact of conjunctural effect as a consequence of Covid 19.

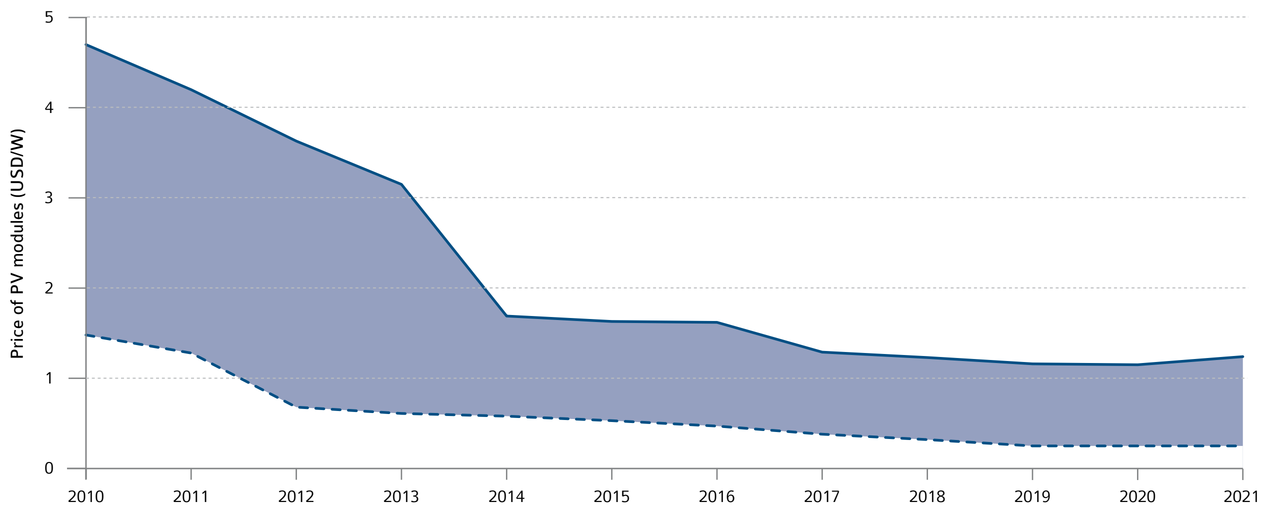
MODULE PRICES / CONTINUED

FIGURE 6.1: PV MDOULES SPOT PRICES LEARNING CURVE (1992-2021)



SOURCE IEA PVPS & BECQUEREL INSTITUTE

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



SOURCE IEA PVPS & OTHERS

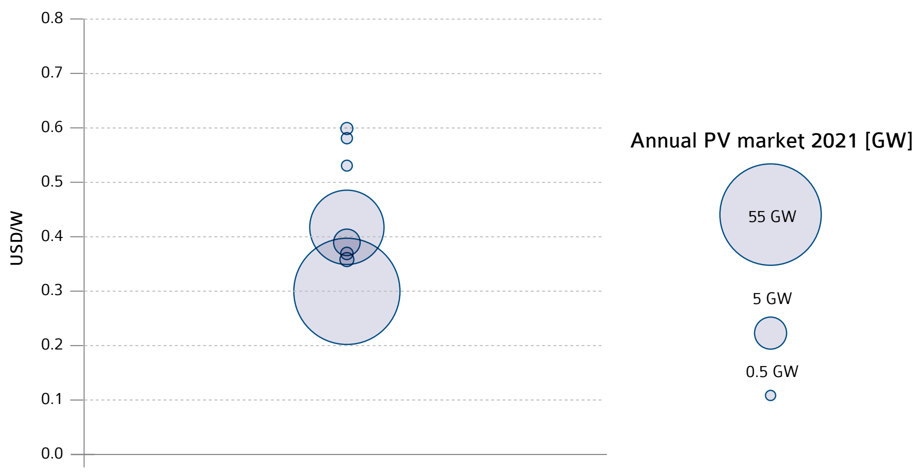
On average, the price of PV modules in 2021 (shown in Figure 6.2) accounted for approximately between 40% and 50% of the lowest achievable prices that have been reported for utility scale systems. In 2021, the lowest price of modules in the reporting countries was slightly above 0,30 USD/W, a significant increase compared to one year before, 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 2021). However, module prices for utility-scale plants have been reported below the average values, anyway up to around 0,25 USD/W at the end of 2021.

The Chinese decision 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 has seen the rise of multiple raw material prices. In particular, PV polysilicon average spot prices significantly during the year, up from around 10 USD/kg in early 2021. Other key raw materials such as PV glass, copper or aluminium maintained their high prices reached at the end of 2020. In addition, the whole PV value chain suffered from the important increase in transport costs.

Prices below 0,25 USD/W can hardly generate benefits 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. It can also be assumed that the most competitive thin film technologies can outperform traditional crystalline silicon ones. The decrease in polysilicon and wafer costs also led to some PV modules' price decreases without cost improvements at cells and modules 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 United States, while average selling prices were in general still in the 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. For more detailed information, the reader is directed to each country's national survey report on the IEA PVPS website (**www.iea-pvps.org/national-survey-reports**).

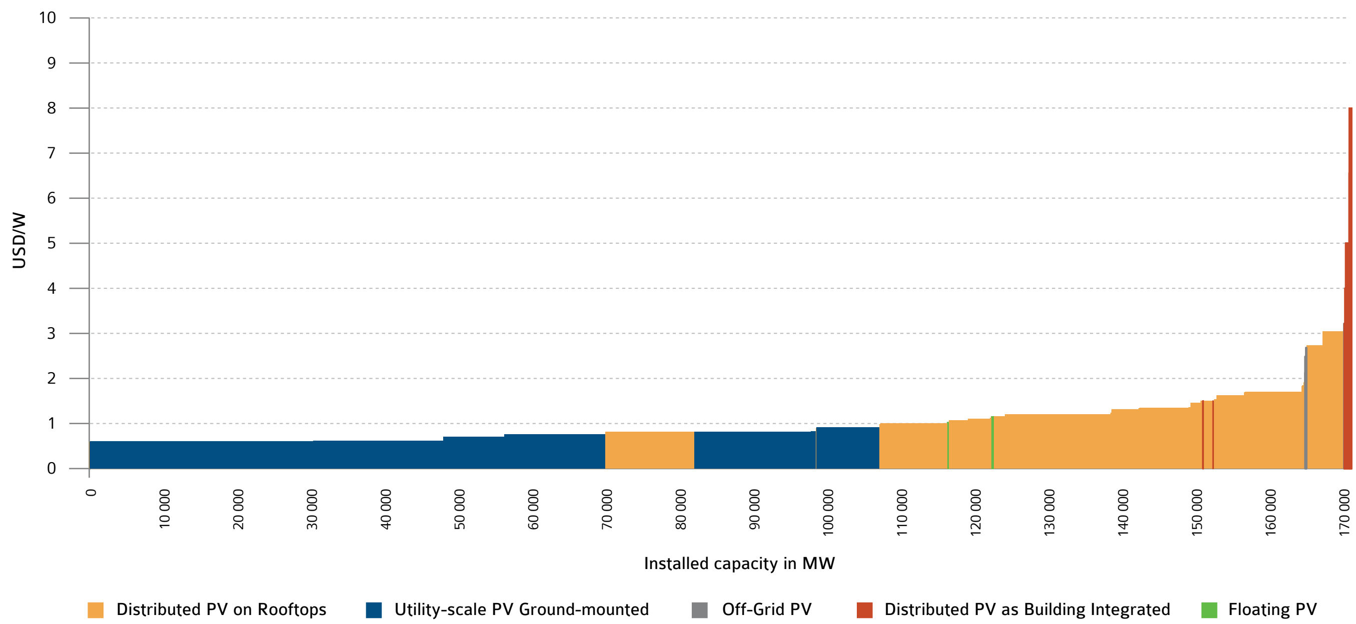
Figure 6.4 shows the range of system prices in the global PV market in 2021. It shows that around 65% of the PV market consists of prices below 1 USD/W. Large distributed PV systems start around 0,75 USD/W while utility-scale PV saw prices as low as 0,55 USD/W. BIPV can be seen as a series of segments 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 2021, 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. The large range of reported prices in Figure 6.5 is a function of the country and project-specific factors. The highest prices haven't been included in the figures given the very low level of installations: in general, off-grid prices have been averaged in the figures for readability reasons.

In 2021, an increased number of floating PV projects have been realized, in particular in Southeast Asia and Europe. Nevertheless, floating PV would require some further developments to identify real-life prices.

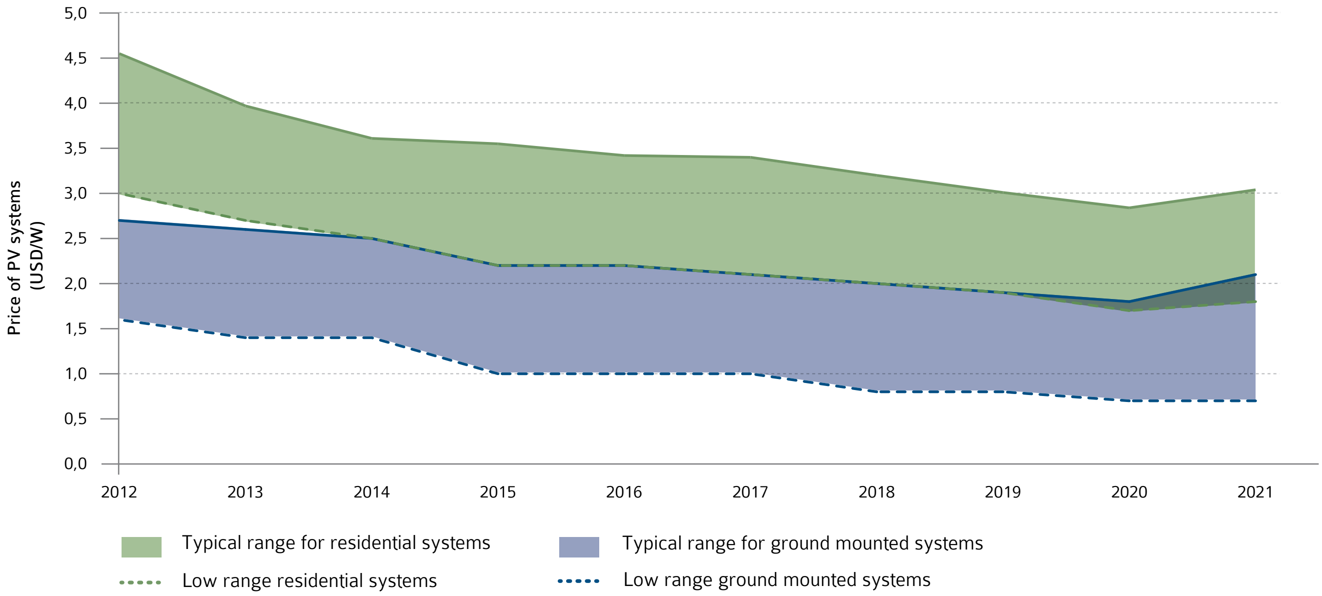
Additional information about the systems and prices reported for most countries can be found in the various National Survey Reports; excluding VAT. More expensive grid-connected system prices are often associated with roof-integrated slates, tiles, building integrated designs or single projects: BIPV systems in general are considered more expensive when using dedicated components, even if prices are also showing some decline.

FIGURE 6.4: 2021 PV MARKET COSTS RANGES



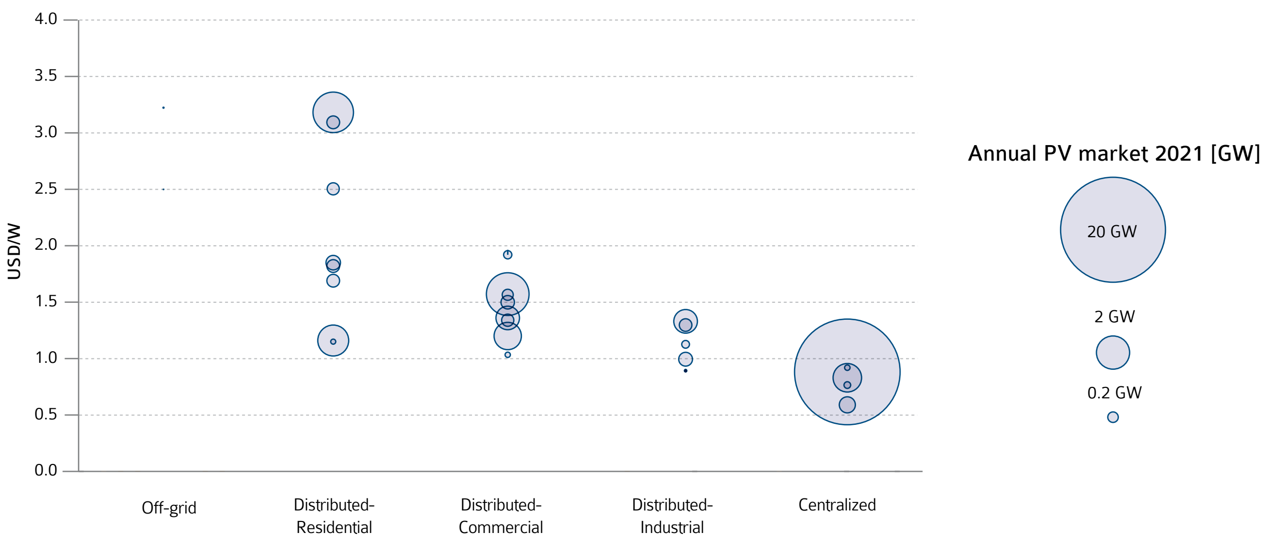
Residential PV systems price ranged from 1,8 USD/W to 3 USD/W in 2021 while utility-scale PV systems prices ranged from 0,35 USD/W to 2,1 USD/W in 2021 according to the data collected.

FIGURE 6.5: EVOLUTION OF RESIDENTIAL AND GROUND-MOUNTED SYSTEMS PRICE RANGE 2012 - 2021 (USD/W)



SOURCE IEA PVPS & OTHERS

FIGURE 6.6: INDICATIVE INSTALLED SYSTEM PRICES IN SELECTED IEA PVPS REPORTING COUNTRIES IN 2021



SOURCE IEA PVPS & OTHERS

SYSTEM PRICES / CONTINUED

The lowest achievable installed price of grid-connected systems in 2021 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 increased in 2021, following the trends of module prices and the balance of the system while soft costs and margins remained stable. Yet, system prices below 0,6 USD/W for large-scale PV systems were common in very competitive tenders, and some report prices down to 0,35 USD/Wp in India. The previously observed trend of price ranges tending to converge, with the lowest prices decreasing at a reduced rate while the highest prices are reducing faster was broken in 2021. Finally, the question of the lowest CAPEX is not always representative of the lowest LCOE: the case of utility-scale PV with trackers illustrates this, with additional CAPEX translating into a significantly higher LCOE. Bifacial costs are not visible in a system cost figure.

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 "gridprice" 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.).

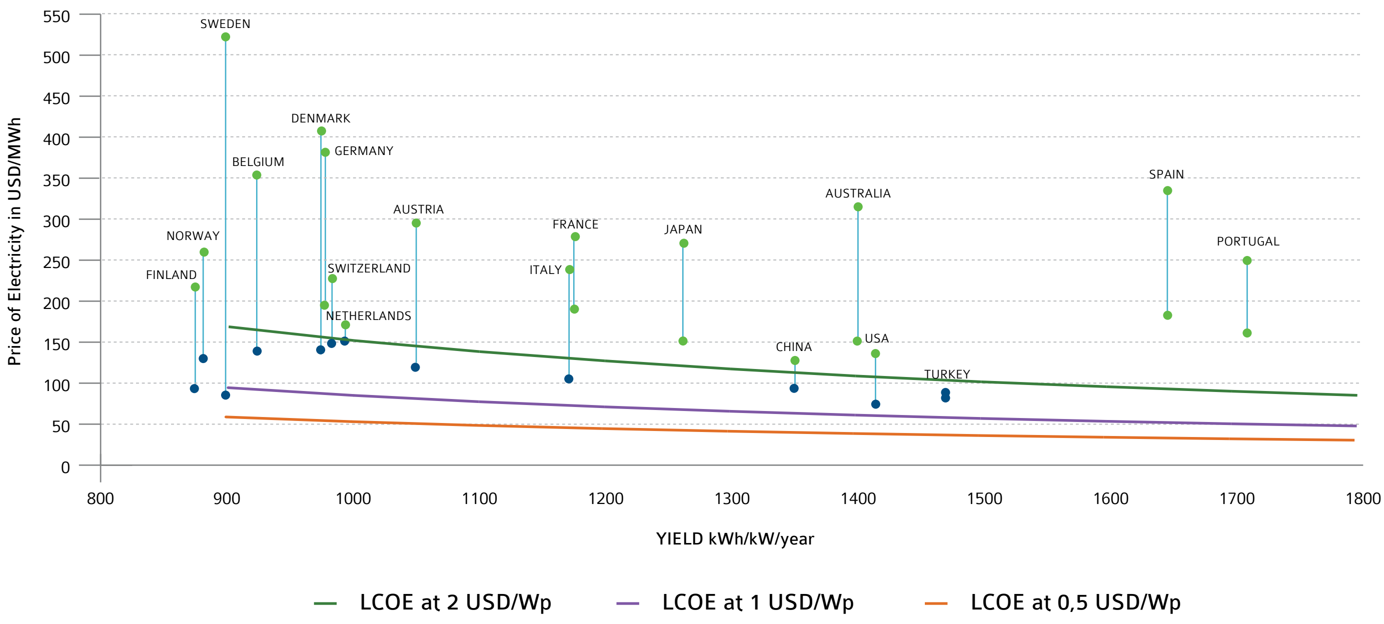
If only a part of the electricity produced can be self-consumed, then the remaining part must be injected into the grid and should generate revenues of the same order as any centralized production of electricity. Today this is often guaranteed for small size installations by the possibility of receiving a FiT (or similar) for the injected electricity. 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 should be considered given the loss of revenues for grid operators or a better understanding of PV positive impacts on the grid should be achieved.

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

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

SOURCE IEA PVPS & OTHERS

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 2021, rising retail electricity prices have further strengthened the competitiveness of PV in a number of countries. 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.

COST OF PV ELECTRICITY / CONTINUED

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. However, 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 2020 electricity prices. Under rising electricity prices, such business models have allowed to take full advantage of the short-term conjunctural favourable situation and this in spite of the PV systems price increase observed in 2021. 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 on 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.

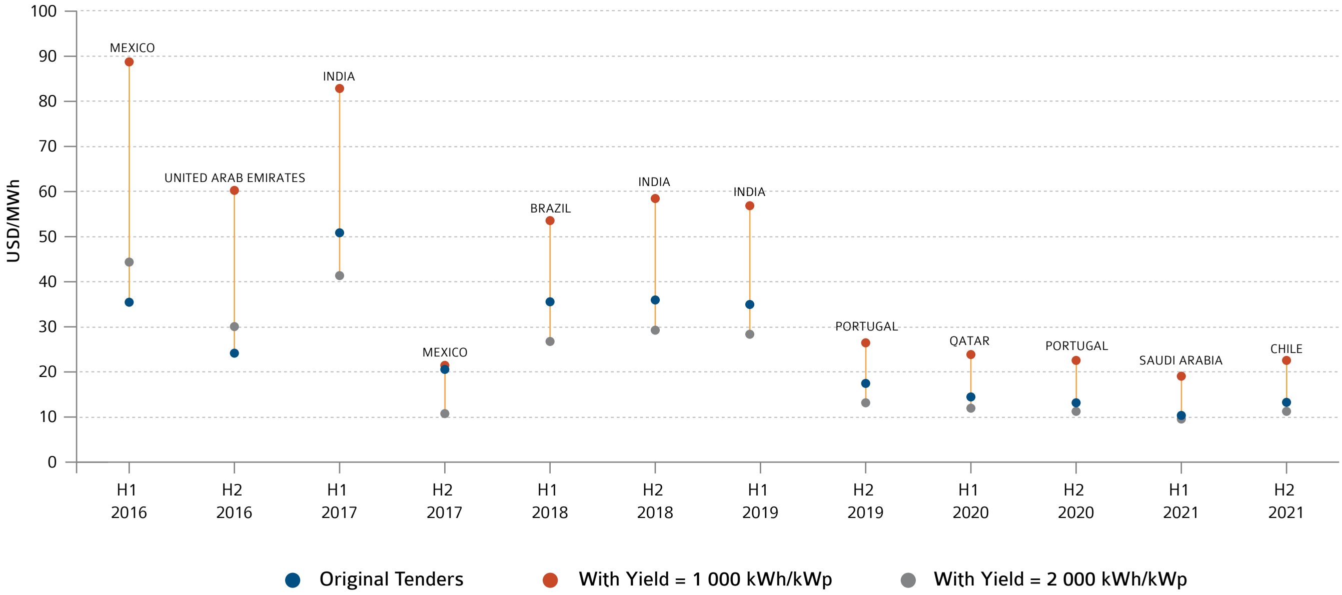
Other off-grid systems are often not replacing existing generation sources but providing electricity in places with no network and no or little use of diesel generators. They represent a completely new way to provide electricity to hundreds of millions of people all over the world.

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 the business model behind is being explored, in particular in Australia, Chile, China, France, Japan, Korea, Portugal and Spain, 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. While the competitiveness with "black" hydrogen seems still unreachable for the time being, 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 increase possibly the PV market significantly outside of the constraints it experiences for the time being.

RECORD LOW TENDERS

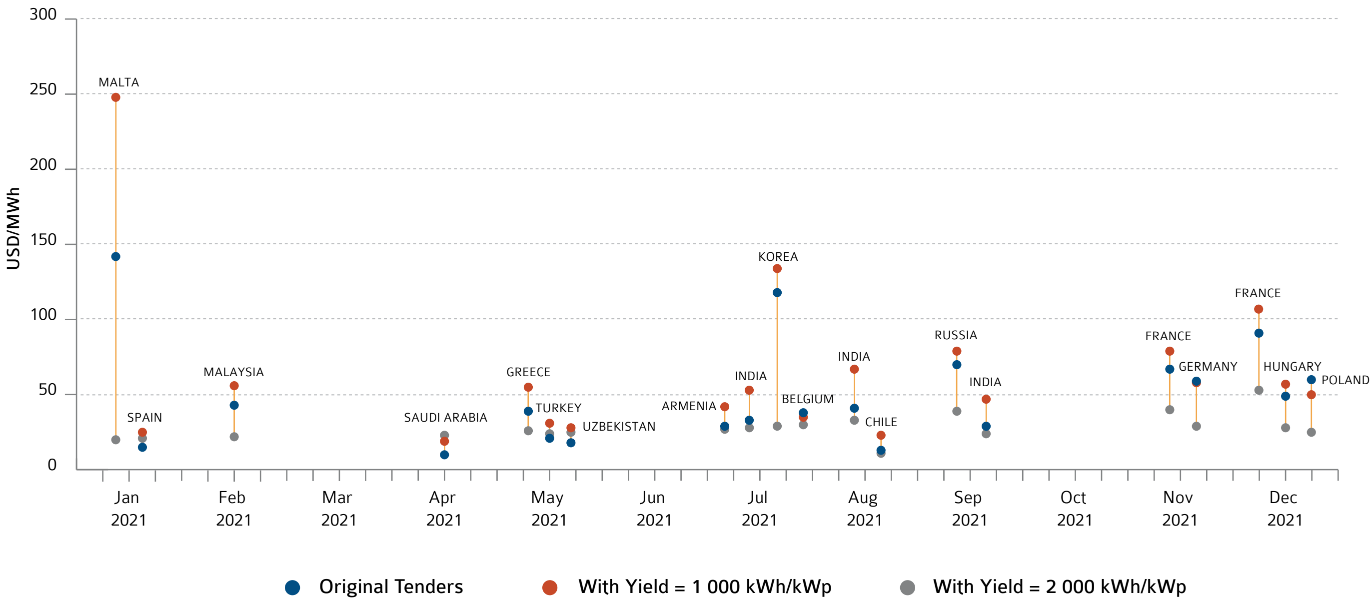
FIGURE 6.8.A: NORMALISED LCOE FOR SOLAR PV BASED ON LOWEST* PPA PRICES 2016 - Q4 2021



* BASED ON LOWEST PPA PRICES PER SEMESTER

SOURCE IEA PVPS & OTHERS

FIGURE 6.8.B: NORMALISED LCOE FOR SOLAR PV BASED ON RECENT PPA PRICES 2021



SOURCE IEA PVPS & OTHERS

COST OF PV ELECTRICITY / CONTINUED

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 were again reached in 2021. 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 an insane market price increase (up to 1 000% increase compared to early 2021) that PV prices 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 constitute anyway 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	10,4	2021
EUROPE	PORTUGAL	13,2	2020
LATIN AMERICA	CHILE	13,3	2021
MIDDLE EAST	UNITED ARAB EMIRATES	13,5	2020
MIDDLE EAST	QATAR	14,5	2020
MIDDLE EAST	SAUDI ARABIA	14,8	2021
EUROPE	SPAIN	15,0	2021
EUROPE	PORTUGAL	17,5	2019
LATIN AMERICA	BRAZIL	17,5	2019
ASIA	UZBEKISTAN	17,9	2021

SOURCE IEA PVPS 8 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 8 OTHERS

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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.

Furthermore, PV electricity production is easy to measure at a power plant but much more complicated to compile for an entire country. First, the installed capacity must be accurately tracked, which requires an effective and consistent approach, especially for distributed and off-grid segments. Second, the electricity production cannot accurately be derived from the installed PV capacity at a certain point in time. Indeed, a system installed at the end of the year will have produced only a small fraction of its theoretical annual electricity output. 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

As an increasing share of the global installed PV capacity is attaining a certain lifetime - with the very first waves of installations dating back to the nineties - decommissioning must be considered to estimate the PV capacity. However, the effect might still be limited at the global scale as less than 0,1% of the cumulative capacity has been installed before the year 2000 and only 6% before the year 2010. Furthermore, when available, official numbers should take decommissioning into account, which is the case for most IEA PVPS countries. In that respect, off-grid numbers in several countries have decreased due to decommissioning. Recycling numbers are underestimating decommissioning due to a vivid (and sometimes barely legal) second-hand market, especially towards Africa.

PV ELECTRICITY PRODUCTION / CONTINUED

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 and thus a standardized approach to the calculation. The combination of temperature corrected PR with the use of Year on Year or STL performs very well compared to others.

Within the IEA PVPS Task 13, a group of experts representing several leading R&D centers, 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.

PV PENETRATION

PV electricity penetration is the ratio between PV electricity production in a country and the electricity demand in that country and is expressed as a percentage. 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 2021.

Real figures might be lower since some installations didn't produce electricity during the entire year, but also since some plants might have experienced production issues, due to technical problems or external constraints (e.g., in France, PV penetration as reported by RTE (French TSO) lies around 3%). The real PV production in a country is difficult to assess, especially when self-consumption and storage enter into consideration. IEA PVPS advocates for governments and energy stakeholders, including grid operators to create accurate databases and measure precisely PV production.

Concerning global PV penetration, with around 946 GW installed worldwide, PV could produce almost 1 229 TWh (see Table 7.1) of electricity on a yearly basis. This represents around 5% of the global electricity demand covered by PV as presented in figure 7.1. Performance losses due to aging of PV plants are not considered at this point.

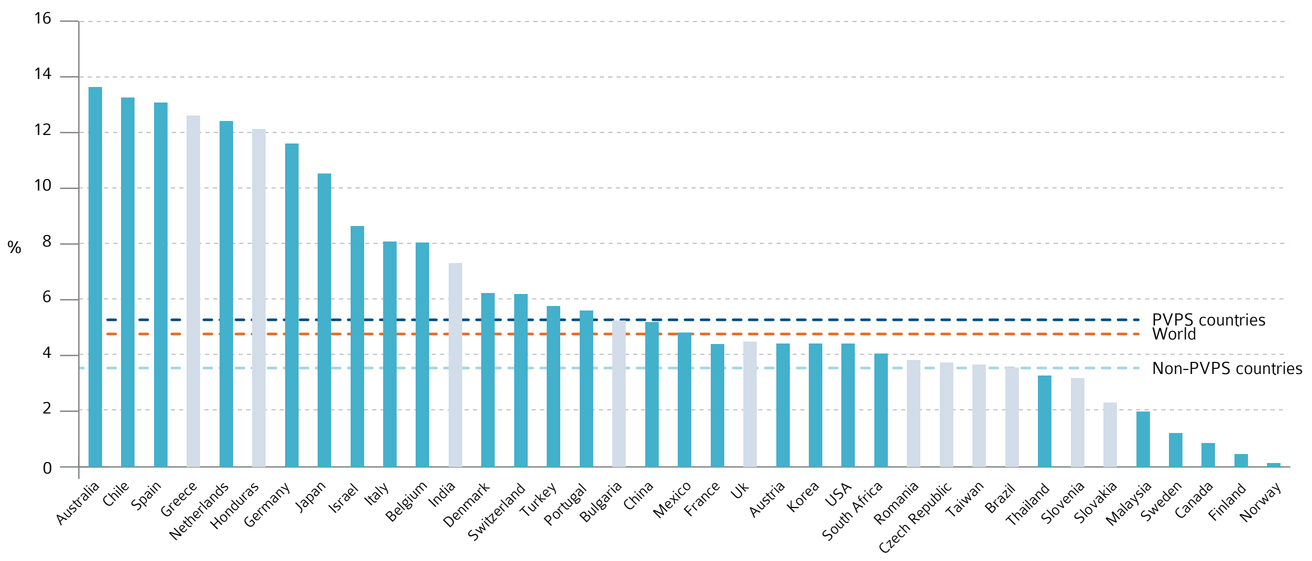
TABLE 7,1: 2021 PV ELECTRICITY STATISTICS IN IEA PVPS COUNTRIES

COUNTRY	FINAL ELECTRICITY CONSUMPTION 2021	HABITANTS 2021	GDP 2021	SURFACE	AVERAGE YIELD	PV CUMULAIVE INSTALLED CAPACITY 2021	PV ANNUAL INSTALLED CAPACITY 2021	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	1 543	7 690 000	1 400	26 035	4 944	36	192	1 011	3	13,6%
AUSTRIA	66	9	477	84 000	1 050	2 783	739	3	83	313	33	4,4%
BELGIUM	82	11	600	33 688	925	7 123	850	7	74	620	211	8,0%
CANADA	562	38	1 991	9 985 000	1 150	4 135	421	5	11	109	0	0,8%
CHILE	79	19	317	756 096	1 699	6 165	2 681	10	140	321	8	13,3%
CHINA	7 714	1 400	17 734	9 634 000	1 300	308 520	54 880	401	39	220	32	5,2%
DENMARK	37	6	397	44 000	975	2 344	718	2	122	399	53	6,2%
FINLAND	81	6	299	390 908	875	413	100	0	18	75	1	0,4%
FRANCE	441	67	2 937	543 965	1 180	16 450	3 350	19	50	245	30	4,4%
GERMANY	503	83	4 223	357 170	978	59 661	5 760	58	69	718	167	11,6%
ISRAEL	68	9	482	20 770	1 750	3 349	935	6	101	360	161	8,6%
ITALY	318	59	2 100	301 336	1 137	22 594	944	26	16	374	75	8,1%
JAPAN	783	126	5 065	377 975	1 050	78 413	6 545	82	52	622	207	10,5%
KOREA	553	52	1 799	100 401	1 137	21 548	4 225	24	81	416	215	4,4%
MALAYSIA	154	33	373	330 621	1 314	2 330	370	3	11	71	7	2,0%
MEXICO	291	130	1 293	1 964 380	1 708	8 199	1 625	14	12	63	4	4,8%
NETHERLANDS	115	18	1 018	41 500	994	14 349	3 632	14	207	818	346	12,4%
NORWAY	127	5	482	385 178	882	205	45	0	8	38	1	0,1%
PORTUGAL	47	10	250	92 225	1 613	1 647	571	3	55	159	18	5,6%
SPAIN	233	47	1 425	505 990	1 646	18 503	4 900	30	105	396	37	13,1%
SWEDEN	140	10	627	407 284	950	1 798	599	2	57	172	4	1,2%
SWITZERLAND	58	9	813	41 285	985	3 656	683	4	79	422	89	6,2%
SOUTH AFRICA	197	60	351	1 219 090	1 733	4 630	458	8	8	77	4	4,1%
THAILAND	190	70	506	1 219 092	1 522	4 078	500	6	7	58	3	3,3%
TURKEY	284	85	815	783 560	1 500	10 917	1 492	16	18	128	14	5,8%
USA	3 930	332	22 996	9 147 281	1 416	123 004	26 873	174	81	371	13	4,4%
WORLD	25 000	7 837	96 100	134 325 435	1 300	173 534	945 354	1 229	22	121	7	4,9%

SOURCE IEA PVPS 8 OTHERS

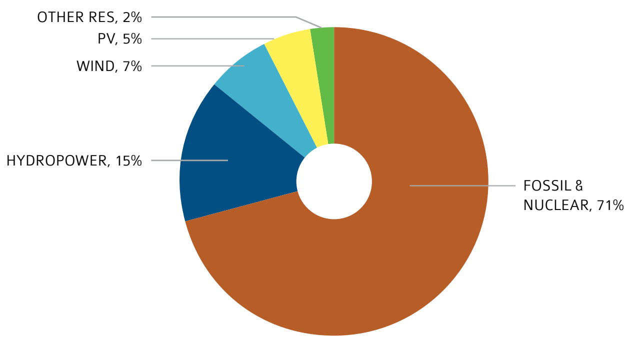
PV ELECTRICITY PRODUCTION / CONTINUED

FIGURE 7.1: PV CONTRIBUTION TO ELECTRICITY DEMAND 2021



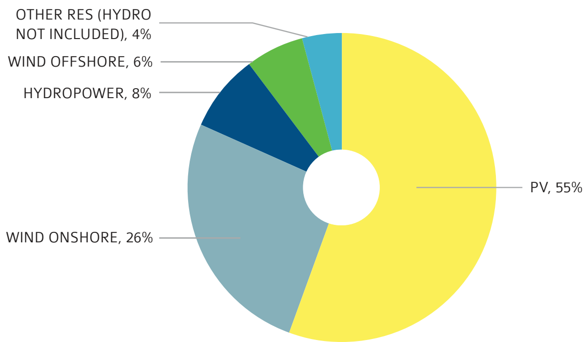
SOURCE IEA PVPS & OTHERS

FIGURE 7.2: SHARE OF RENEWABLE IN THE GLOBAL ELECTRICITY PRODUCTION IN 2021



SOURCE REN21, IEA PVPS

FIGURE 7.3: NEW RENEWABLE INSTALLED CAPACITY IN 2021



SOURCE REN21, IEA PVPS

PV INTEGRATION AND SECTOR COUPLING

THE ENERGY STORAGE MARKET

In general, battery storage is seen by some as an opportunity to solve some 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. However, the adoption of batteries is on the rise both in the residential segments and in the commercial segments as more and more consumers are willing to maximise their self-consumption and to optimize their consumption profile.

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. The displacement of energy towards the evening peak allows benefiting from higher wholesale market prices and changes the injection pattern of PV. An increasing number of tenders are requiring PV to be installed with storage.

Globally, the largest part of batteries sold are used for transportation in EVs, stationary storage remains the exception and volumes remain small. 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. In addition, 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.

THE ELECTRIFICATION OF TRANSPORT

The role of PV as an enabler of that energy transition is more and more obvious and the idea of powering mobility with solar is becoming slowly a reality as an increasing number of commercial partnerships combine EV charging stations to solar systems for private and public use.

PV could make EVs greener faster. The shift from fossil fuels to electricity for individual transportation and especially cars and light-duty vehicles is a necessary step towards the decarbonization of the transport sector. However, the real emissions of GHG for EVs depend on the power mix used to charge cars. In countries with a power mix heavily relying on fossil fuels, the emissions will remain higher than in countries with a renewable or carbon-free mix. In that respect, some initiatives popped up in the recent months in Europe to connect the fast development of the EV market to renewables and especially PV. The idea to propose to the automotive industry to decarbonize completely electric vehicles would imply to sell renewable energy contracts or, easier, shares in PV plants, when an EV is brought to the market.

From PV to VIPV and VAPV

With its distributed nature, PV fits perfectly with EV charging during the day when cars are stationed in the offices parking or at home. Such slow charging is also highly compatible with distribution grid constraints. Finally, the integration of PV in the vehicles themselves, the so-called VIPV, also offers opportunities to alleviate the burden on the grid, increase the autonomy of EVs and connects the automotive and PV sectors. 2021 showed announcements from several manufacturers, especially in **Japan** and **Korea**, but also **Germany** and the **Netherlands**, for VIPV systems integrated in EVs. Recently, some first high-end commercial products have become available in Europe. The IEA PVPS Task 17 deals with this fast emerging subject.

PV INTEGRATION AND SECTOR COUPLING / CONTINUED

THE ELECTRIFICATION OF HEATING AND COOLING

The recent development of PV self-consumption especially in Europe has created new opportunities to use solar electricity for specific buildings appliances.

Among others, even if the solar production is not directly linked to consumption load in the case of space heating, it is becoming a real source of interest to use solar PV electricity to feed electric domestic hot water tanks for instance. Hot water tanks can also serve as storage and can be successfully combined with a heat pump.

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 allow to increase the self-consumption and to store the PV production.

More single household owners with PV systems take an interest in those in order to increase self-consumption. Specific recommendations exist for connection and metering of storage systems in Switzerland for instance.

Another very promising segment in the use of solar PV electricity is the use for cooling. Beyond Europe, a lot of countries are very 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.

China is at the forefront worldwide for the supply of PV air conditioning solutions, mainly in the domestic household segment.

For larger coupling, no real commercial products are available. Nevertheless, more and more design 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, 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, namely solar PV and solar thermal, for cooling is profiting from July 2020 a specific IEA SHC Task called Task 65 (**https://task65.iea-shc.org/**) which will focus worldwide on innovative ways to adapt and develop existing technologies (solar and heat pumps) for sunny and hot climates.

GREEN HYDROGEN

Green hydrogen refers to hydrogen produced from renewable sources, oppositely to hydrogen produced from fossil fuels or nuclear power. Hydrogen is increasingly seen as a partial answer to decarbonize some sectors (especially the maritime sector and long distance, heavy weight road transport. In that respect, green hydrogen is part of numerous research programs and early industrialization projects have been initiated in 2021. Produced by competitive PV, transformed in hydrogen for direct use, or under its derivatives (ammonia, etc.), it can also be stored and reproduce electricity, even if the overall efficiency decreases significantly.

ANNEXES

ANNEX 1: AVERAGE 2021 EXCHANGE RATES

COUNTRY	CURRENCY CODE	EXCHANGE RATE IN 2021 (1 USD =)
AUSTRALIA	AUD	1,332
CANADA	CAD	1,254
CHILE	CLP	760,36
CHINA	CNY	6,452
DENMARK	DKK	6,29
EUROZONE	EUR	0,846
ISRAEL	ILS	3,232
JAPAN	JPY	109,817
KOREA	KRW	1144,883
MALAYSIA	MYR	4,144
MEXICO	MXN	20,284
MOROCCO	MAD	8,995
NORWAY	NOK	8,598
SOUTH AFRICA	ZAR	14,789
SWEDEN	SEK	8,584
SWITZERLAND	CHF	0,914
THAILAND	THB	31,997
TURKEY	TRY	8,904
UNITED STATES	USD	1

SOURCE IRS

ANNEXES

ANNEX 2: CUMULATIVE INSTALLED PV CAPACITY (MWp) FROM 1992 TO 2021

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
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	26 035
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
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
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	4 135
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
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
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	2 344
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	413
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	16 450
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	49 016	53 901	59 661
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
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	19297	19 682	20 108	20 865	21 650	22 594
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
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	21 548
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
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
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
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
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	205
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
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
SPAIN	0	0	0	0	0	0	0	0	0	2	5	11	21	43	125	618	3 351	3 392	3 829	4 233	4 532	4 638	4 661	4 707	4 762	4 897	5 159	10 075	13 603	18 503
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	1 798
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
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	35 78	4 078
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
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	18321	25 821	40 973	51 818	62 498	76 274	96 131	123 004
REST OF EU COUNTRIES	0	0	0	0	0	0	0	0	0	0	1	11	21	23	34	42	68	505	2 222	2 908	5 039	7420	7 820	8 218	8 600	8 980	9 862	11 715	16 777	23 321
TOTAL IEA PVPS	50	65	90	115	150	206	271	372	572	783	1 142	1 563	2 694	4 106	55 26	7 889	14 177	22 191	38 794	68 234	95 613	130 165	165 604	207 614	274 909	359 002	444 009	527 065	640 989	776 869
TOTAL NON IEA PVPS	0	0	0	0	0	0	0	0	1	8	14	23	33	45	67	94	178	319	796	2 812	5 237	8 449	13 133	21 612	31 107	49 874	69 492	99 294	130 830	168 485
TOTAL	50	65	90	115	150	206	271	372	573	790	1 156	1 587	2 727	4 152	5 593	7 983	14 355	22 510	39 590	71 046	100 850	138 614	178 736	229 225	306 016	408 876	513 502	626 359	771 819	945 354

SOURCE IEA PVPS, BECQUEREL INSTITUTE 8 OTHERS

ANNEXES / CONTINUED

ANNEX 3: ANNUAL INSTALLED PV CAPACITY (MWp) FROM 1992 TO 2021

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
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	4 944
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
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
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	421
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
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
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
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	100
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	3 350
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	5 760
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
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
JAPAN	19	5	7	12	16	32	42	75	122	123	184	223	272	290	287	210	225	483	991	1 296	1718	6 968	9 740	10 811	7 889	7 460	6 662	7030	8 676	6 545
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	4 225
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
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
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
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
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	45
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
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
SPAIN	0	0	0	0	0	0	0	0	0	2	3	6	10	32	82	493	2 733	41	437	404	299	106	23	46	55	135	262	4 916	3 528	4 900
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	599
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
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
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
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	26 873
REST OF EU COUNTRIES	0	0	0	0	0	0	0	0	0	0	0	10	10	2	11	7	27	437	1 717	686	2 130	2 381	400	398	382	380	882	1 853	5 062	6 546
TOTAL IEA PVPS	50	16	25	25	35	56	65	101	199	211	360	421	1 130	1 423	1 420	2 363	6 288	8 014	16 603	29440	27 382	34 552	35 438	42 010	67 295	84 093	85 007	83 057	113 925	1358 80
TOTAL NON IEA PVPS	0	0	0	0	0	0	0	0	1	7	6	9	10	12	21	27	85	141	477	2 016	2 422	3 212	4 685	8 478	9 485	18 767	19 618	29 801	31 537	37 654
TOTAL	50	16	25	25	35	56	65	101	200	218	366	430	1 140	1 435	1 441	2 390	6 372	8 155	17 080	31 456	29 805	37 765	40 123	50 488	76 780	102 860	104 625	112 858	145 461	173 534

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