Technology Collaboration Programme
by IEA

International Energy Agency
Photovoltaic Power Systems Programme

Task 1 Strategic PV Analysis and Outreach

PVPS

TRENDS IN PHOTOVOLTAIC APPLICATIONS 2020

Report IEA-PVPS T1-38:2020

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

Visit us at: www.iea-pvps.org

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AgriPV trial installation in France. © Sun'Agri

ISBN 978-3-907281-01-7: Trends in Photovoltaic Applications 2020.

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 2019 and analyses trends in the implementation of PV power systems between 1992 and 2019. 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.

ACKNOWLEDGEMENT

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 Mary Brunisholz, IEA PVPS and NET Ltd.

FOREWORD

On behalf of the IEA PVPS Technology Collaboration Programme, I am pleased to present the 25th edition of the International Survey Report on Trends in Photovoltaic (PV) Applications 2020.

"Solar is the new king of the electricity markets," was one of the first key statements of the IEA Executive Director Fatih Birol when launching the most recent IEA World Energy Outlook in October 2020, acknowledging that solar PV electricity is becoming the cheapest source of new electricity in many countries around the world and will therefore continue to grow strongly over the decades to come.

The IEA PVPS Task 1 expert group "Strategic PV Analysis and Outreach" carefully prepared this report, tracking the most recent developments in PV markets and industry around the world. With a particular focus on IEA PVPS members, the report aims to provide a detailed picture of the worldwide and country-specific photovoltaic market trends, the various drivers and policies, the status of the industry and discusses the increasing role of PV in the energy system. This year's report covers the market and industry development up to 2019 and highlights some more recently observed trends.

112 GW of PV power systems have been installed globally in 2019 (2018: 103 GW), bringing the total installed capacity to over 623 GW (2018: 512 GW). We observe a confirmation of the strong role of PV deployment in Asia. In spite of a further reduction in China's PV market (from 44,3 GW in 2018 to 30,1 GW in 2019), this country maintained its leadership, both in annual as well as total installed capacity. For 2019, China's annual installed PV capacity is followed by the United States (13.3 GW), India (10,1 GW), Japan (7,0 GW) and Vietnam (4,8 GW). Eighteen countries installed more than 1 GW in 2019 and 40 countries reached a cumulative capacity of 1 GW and more. The countries with the ten largest annually installed PV capacities account for about 76% of the total annual installed capacity of 112 GW (down from 87% of 103 GW installed in 2018). The number of countries that are entering the PV market with significant market developments is thus clearly increasing, which is an encouraging sign and one which makes the global PV market more robust.

On the cost side, further record PPAs have been announced for large scale PV systems at below 1,4 USDcents per kWh, confirming the increasing competitiveness that PV can reach under the best conditions. In spite of these very competitive prices in a favourable market environment, the regulatory framework and its further evolution towards market mechanisms remain significantly important for the further development of worldwide PV markets.

As in recent years, utility-scale PV systems have dominated the PV market in 2019; however, distributed PV systems, namely on commercial and industrial premises, are becoming more important in many countries, due to their favourable economics; in particular when combined with increased self-consumption and battery storage. New market segments are emerging such as floating PV or agri-PV, the combination of PV with agriculture. Off-grid PV, while small in absolute terms of installed capacity, continues to grow in large numbers in various countries in Asia and Africa.

As PV markets grow and will continue to do so in the coming years, other benefits than purely electricity services emerge including economic, climate change and broader energy system related benefits, including – in the longer term – for power-to-x (e.g. heat, fuel). First significant benefits can be quantified, such as the avoided CO_2 emissions.

As the world economy and in particular energy markets are going through difficult times due to the COVID-19 pandemic, positive signs also emerge. PV is becoming more competitive, more versatile and more robust, emerging as a key technology of the ongoing energy transition!

These are just a few highlights of the wealth of information that this 25th edition of the IEA PVPS Trends report hopes to provide to you!

Stefan Nowak
Chairman
IEA PVPS Programme

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TOTAL BUSINESS VALUE IN PV SECTOR IN 2019

$135 BILLION

TOP 5 PV MARKETS IN 2019

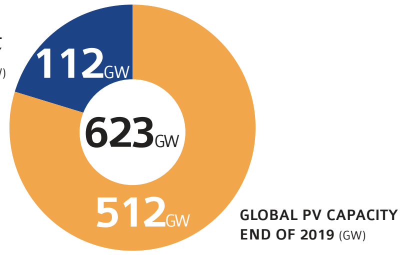
CHINA	30,1 GW
EU	15,9 GW
USA	13,3 GW
INDIA	10,1 GW
JAPAN	7,0 GW

PV CONTRIBUTION TO ELECTRICITY DEMAND

3,3 %

Share of PV in the global electricitiy demand in 2019

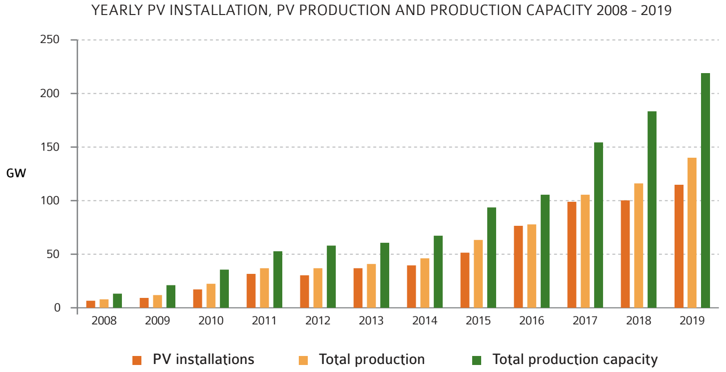
GLOBAL PV CAPACITY END OF 2019



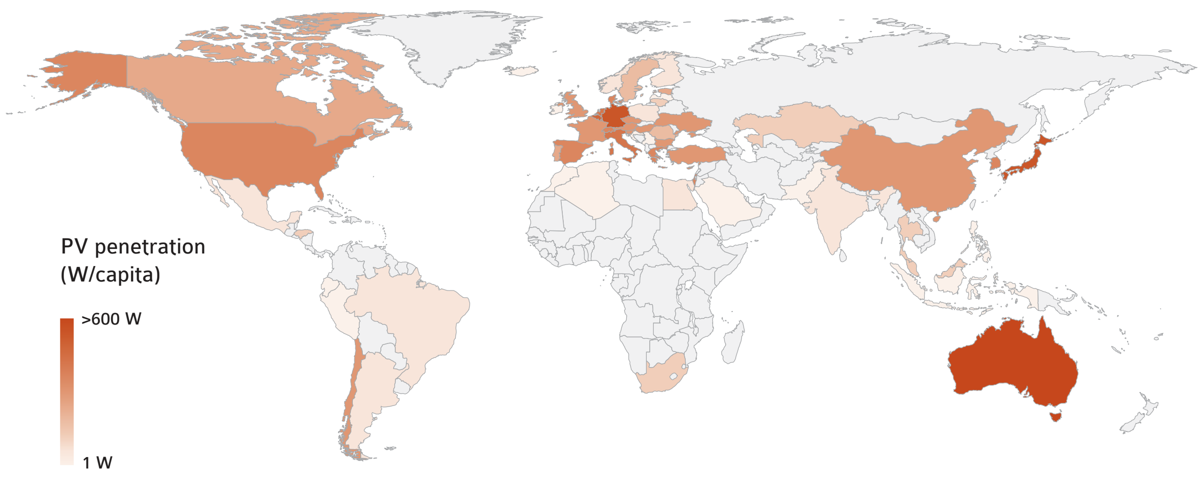
CLIMATE CHANGE IMPACTS

700

millions of tons of CO_2 **saving** every year,



PV PENETRATION PER CAPITA IN 2019



40 COUNTRIES HAD REACHED AT LEAST **1 GWp** IN 2019

PV POWER PER CAPITA

1. AUSTRALIA (644 Wp)
2. GERMANY (589 Wp)
3. JAPAN (500 Wp)

18 COUNTRIES INSTALLED AT LEAST **1 GWp** IN 2019

SOURCE IEA PVPS AND OTHERS

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INTRODUCTION TO THE CONCEPTS AND METHODOLOGY

PV TECHNOLOGY

Photovoltaic (PV) devices convert light directly into electricity and should not be confused with other solar technologies such as concentrated solar power (CSP) or solar thermal for heating and cooling. The key components of a PV power system are various types of photovoltaic cells (often called solar cells) interconnected and encapsulated to form a photovoltaic module (the commercial product), the mounting structure for the module or array, the inverter (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) have gained a lot of traction in the last years. 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 24% (single-junction). 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 average conversion efficiency around 18%-20% 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. Thin-film materials commercially used are cadmium telluride (CdTe), and copper-indium-(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

PV TECHNOLOGY / CONTINUED

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 2019, 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 500 W, depending on the technology and the size. Specialized products for building integrated PV systems (BIPV) exist, 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.[1]

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 aiming 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 way that they fill multiple functions usually devoted to conventional building envelope solutions.

Bifacial PV modules are collecting light on both sides of the panel. When mounted on a surface which albedo reflects enough light, the energy production increase is estimated to a maximum of 15% with 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. The global capacity installed is estimated at 5,4 GW at the end of 2019 and is expected to take growing market shares in the coming years.

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.

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.

VIPV or vehicle integrated PV. The integration of highly efficient 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.

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.

1 Source: https://www.nrel.gov/pv/module-efficiency.html

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.

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 for instance. Large-scale hybrids can be used for large cities powered today by diesel generators and have been seen, for instance in central Africa, often in combination with battery storage.

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.

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.

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PV MARKET DEVELOPMENT TRENDS

Since the early beginnings of the PV market development, over 623,2 GW of PV plants have been installed globally, of which almost 72% has been installed over the last five years. Over the years, a growing number of markets started to contribute to global PV installations, and the year 2019 closed with a record number of new countries installing significant PV numbers.

PV installation data

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.

THE GLOBAL PV INSTALLED CAPACITY

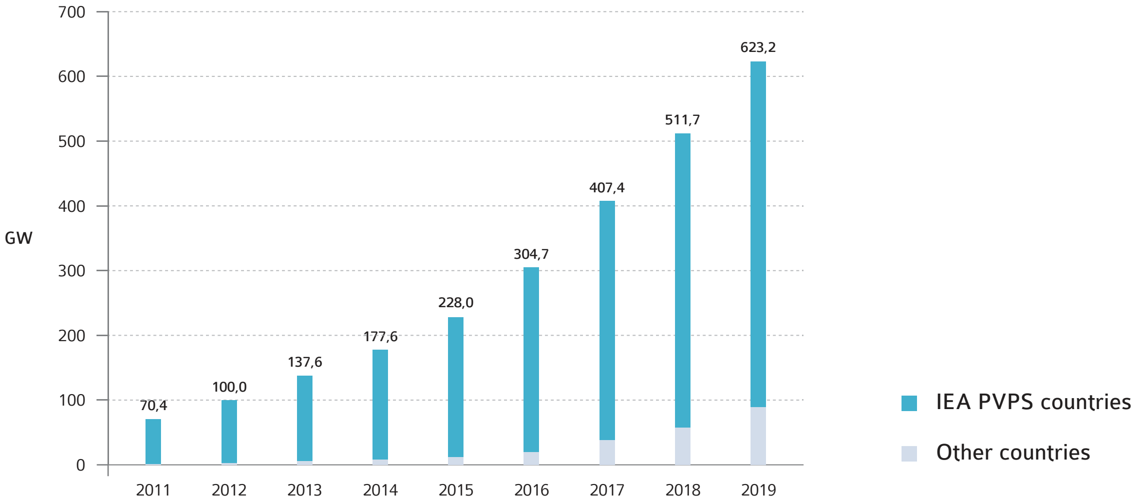
At the end of 2019, the global PV installed capacity represented 623,2 GW of cumulative PV installations.

Presently it appears that 111,6 GW represented the minimum capacity installed during 2019 with a reasonably firm level of certainty.

The IEA PVPS countries represented 509,9 GW of the total installed capacity. The IEA PVPS participating countries are Australia, Austria, Belgium, Canada, Chile, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Mexico, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America.

The other key markets that have been considered and which are not part of the IEA PVPS Programme, represented a total cumulative capacity of 113,4 GW at the end of 2019. Amongst them, India covered over one third of that capacity with 42,9 GW. The rest was mainly located in Europe and partly related to historical installations and increasingly to emerging markets: UK with almost 13,4 GW, Ukraine with 4,9 GW, Greece with 2,8 GW, the Czech Republic with 2,0 GW installed, Romania with 1,4 GW, Poland with almost 1,3 GW and Bulgaria just above the 1 GW mark. The other major countries that accounted for the highest cumulative installations at the end of 2019 and that are not part of the IEA PVPS programme are: Vietnam with an estimated 4,8 GW, Brazil with 4,5 GW, and Taiwan with 4,3 GW. Numerous countries all over the world have started to develop PV but few have yet reached a significant development level in terms of cumulative installed capacity outside the ones mentioned above.

FIGURE 2.1: EVOLUTION OF CUMULATIVE PV INSTALLATIONS



SOURCE IEA PVPS & OTHERS.

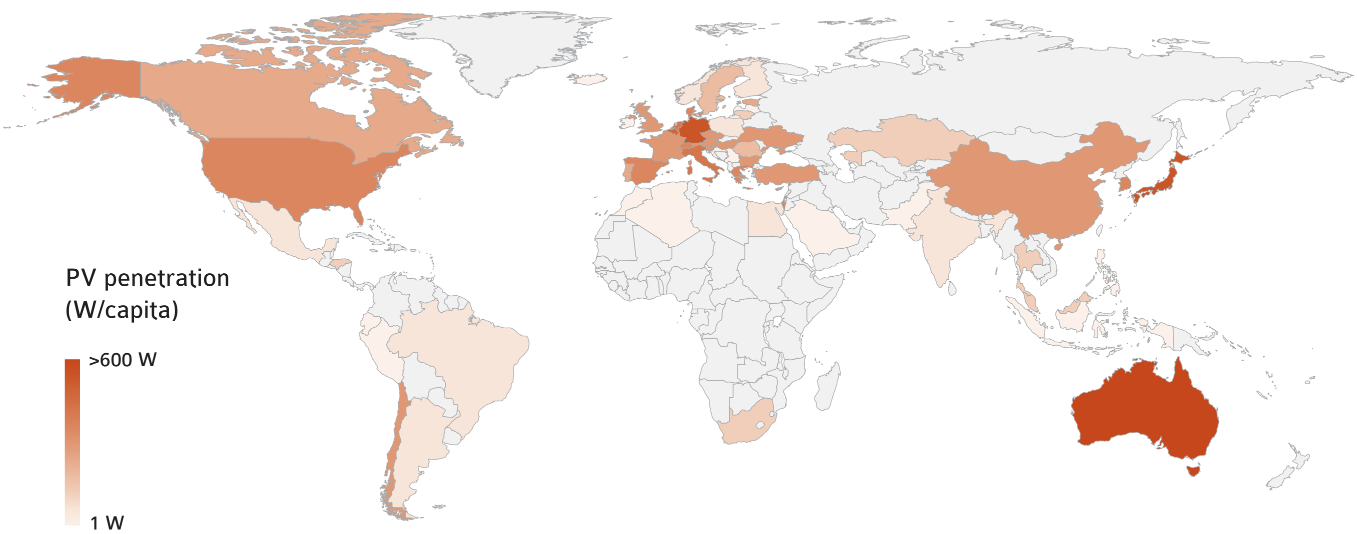
PV PENETRATION PER CAPITA

Figure 2.2 shows PV penetration per inhabitant at the end of 2019, in watts per inhabitant.

In just a few years Australia has reached the highest installed PV capacity per inhabitant with 644 W/cap. Germany is second with 589 W/cap. Japan comes next with 500 W/cap, as it still exceeds the installed capacities per inhabitant in Belgium (425 W/cap). The Netherlands comes in at the 5th place with 396 W/cap, followed by Italy (346 W/cap). Malta and Switzerland come next with respectively 298 and 295 W/cap. Greece and Denmark are closing the top 10 with 262 and 234 W/cap.

Other countries with a PV penetration above 200 W/cap are Luxembourg, the United States, Korea, Spain, Czech Republic and Hungary.

FIGURE 2.2: PV PENETRATION PER CAPITA IN 2019



SOURCE IEA PVPS & OTHERS.

THE GLOBAL PV INSTALLED CAPACITY / CONTINUED

MARKET EVOLUTION

The IEA PVPS countries installed at least 77,9 GW in 2019. While they are more difficult to track with a high level of certainty, installations in non-IEA PVPS countries contributed an amount of 33,7 GW. The noteworthy trend of 2019 is the growth of the global PV market despite the Chinese market slow-down for a second year in a row. As in 2018, the rise of emerging markets contributed to this market growth in 2019.

For the seventh year in a row, China was in first place and installed more than 30,1 GW in 2019, according to China's National Energy Administration; an installation level that is significantly lower than the 44,3 GW and 52,9 GW newly installed capacity in the country in 2018 and 2017, respectively. The total installed capacity in China reached 205,2 GW, and by that the country kept its market leader position in terms of total installed capacity. The Chinese market represented 27% of the global installation in 2019, a significant decrease compared to the three previous years, especially in 2017, where the market share of China reached 51%.

Second was the European Union which experienced growth for the second year in a row with 15,9 GW, coming closer to the 23,2 GW recorded in 2011. Spain (4,7 GW), Germany (3,8 GW) and the Netherlands (2,4 GW) were the key markets this year, followed by France (below 1,0 GW) and several others.

Third was United States with 13,3 GW installed, a significant growth compared to 2018, marking 2019 the second largest single year increase in installations in the U.S. Both the utility sector installations and the residential market increased over 2018 installation levels (with respectively 37% and 15%). At the end of 2019, the U.S. reached 75,9 GW of cumulative installed capacity.

India was in fourth place with 10,1 GWdc installed, out of which a large part was installed as utility-scale plants. The official number has been recalculated based on official AC data using IEA PVPS assumptions on AC-DC ratio. The cumulative capacity installed is of 42,9 GWdc at the end of 2019.

The market in Japan is rather stable as the installations slightly increased to 7,0 GW in 2019, which is not that far from the record level of 10,8 GW in 2015.

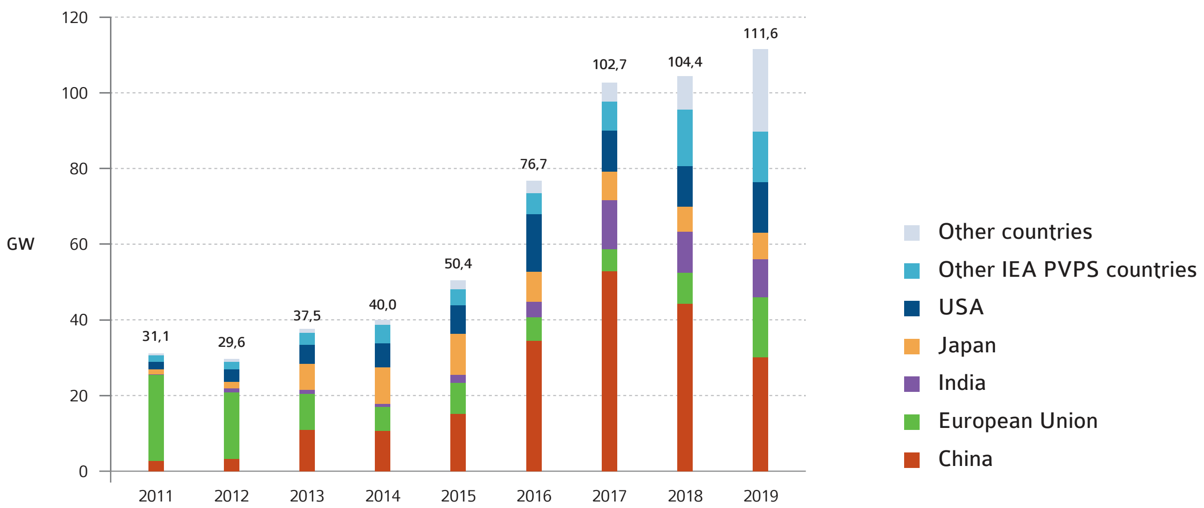
Together, these five leading individual or block of countries represented 57% of all installations recorded in 2019, a considerable reduction compared to 73% in 2018. In terms of cumulative installed capacity these countries represent over 70% of the global capacity. This shows that the global PV market concentration is decreasing, with new markets contributing increasingly to global installation numbers.

Heading the top 10 countries, China, the USA, India and Japan are followed by Vietnam which installed 4,8 GW in 2019 through its successful FIT policy which led to five times more installations than initially planned by the government by 2020

Australia that installed almost 4,8 GW in 2019, 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 16,3 GW at the end of 2019.

Spain regained market confidence of investors mainly through centralized tenders and corporate PPAs, in total almost 4,8 GWdc have been installed in 2019, a major increase compared to the last 10 years. The cumulative capacity in the country nearly doubled as 9,9 GWdc were operational at the end of 2019.

FIGURE 2.3: EVOLUTION OF ANNUAL PV INSTALLATIONS



SOURCE IEA PVPS & OTHERS.

Germany (ninth globally as a country) scored the second rank amongst European countries. It saw its annual installed capacity grow to 3,8 GW, with a significant market development for several years in a row. The total installed PV capacity reached 49,0 GW at the end of 2019.

In the tenth position comes Ukraine where PV installations finally advanced in 2019 after some years of slow development. In total around 3,5 GW were installed, most of which were utility-scale plants under tenders and to a lesser extent, installations in the distributed segments through a net-metering scheme.

Together, these 10 countries cover 75% of the 2019 annual world market, a sign that the growth of the global PV market has been driven by a limited number of countries again, however less than in previous years as 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. However, as shown in Figure 2.4, the market concentration steadily decreases as new markets are starting to emerge, which allows a market stabilization. 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.

The level of installation required to enter the top 10 have increased steadily since 2014: from 843 MW to 1,5 GW in 2018 and 3,1 GW in 2019. This reflects the global growth trend of the solar PV market.

Other countries experienced a significant development of PV in 2019, with part of them having reached the top ten in previous years such as Brazil, Mexico and the Netherlands.

Korea installed 3,1 GW in 2019, again a major increase compared to previous years, mostly with utility-scale plants.

For the first time, Egypt appears in the GW-scale markets. It added 2.5 GWdc of solar PV capacity in 2019 mainly thanks to a new park of utility-scale PV plants.

The Netherlands follow with 2,4 GW, a record level for that small country with scarce available land: a large part of the development came from rooftop applications, driven by self-consumption policies and tender processes.

In Latin America, the market in Brazil was driven both by distributed and centralized applications: in total 2,1 GWdc were installed in 2019.

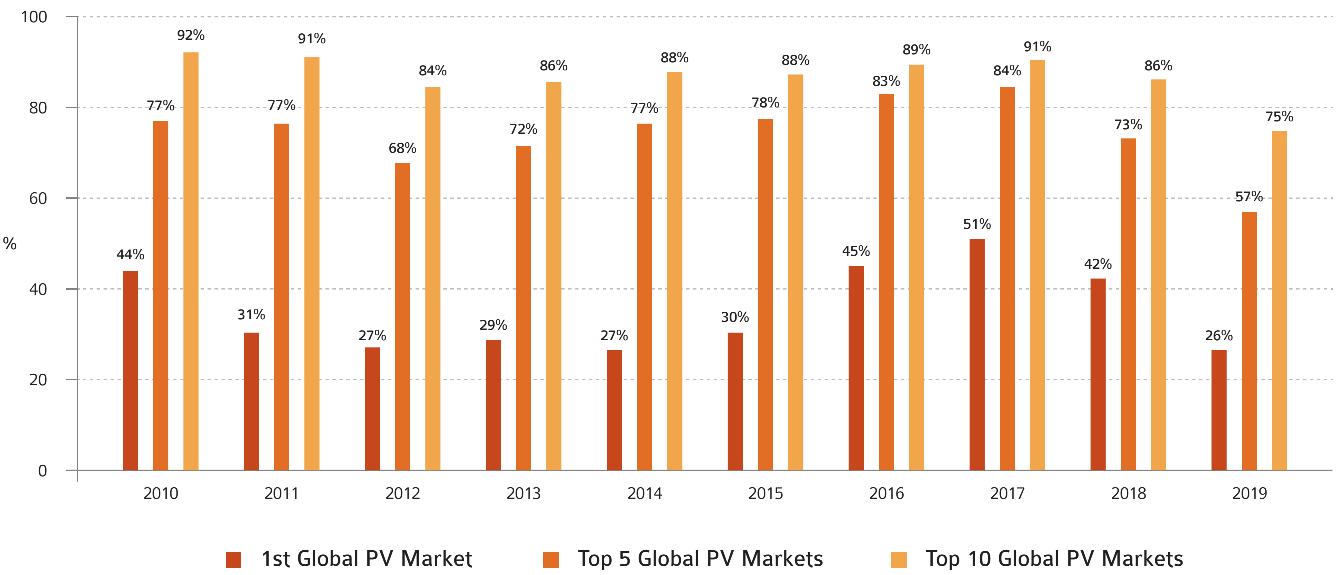
In the UAE, around 2 GW came online in 2019 through large-scale tenders, amongst the most competitive globally. Self-consumption polices didn't contribute much but could represent a complementary driver in the near future.

Mexico's installations reached 1,9 GWdc in 2019, in a complex policy environment, which might put the brakes on its market in the coming years.

Around 1,6 GW of mostly distributed PV was installed in Taiwan in 2019, and more are expected to come online in 2020.

Finally above the GW threshold, Turkey installed around 1,4 GWdc of solar PV in 2019.

FIGURE 2.4: EVOLUTION OF MARKET SHARE OF TOP COUNTRIES



SOURCE IEA PVPS & OTHERS.

THE GLOBAL PV INSTALLED CAPACITY / CONTINUED

TABLE 2.1: EVOLUTION OF TOP 10 PV MARKETS

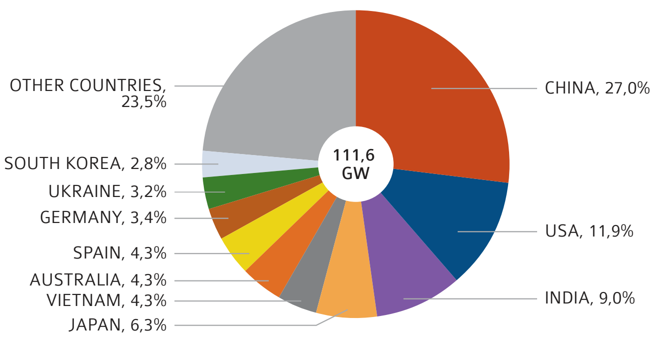
RANKING	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1.	GERMANY	ITALY	GERMANY	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA	CHINA
2.	ITALY	GERMANY	ITALY	JAPAN	JAPAN	JAPAN	USA	INDIA	INDIA	USA
3.	CZECH REP.	CHINA	CHINA	USA	USA	USA	JAPAN	USA	USA	INDIA
4.	JAPAN	USA	USA	GERMANY	UK	UK	INDIA	JAPAN	JAPAN	JAPAN
5.	FRANCE	FRANCE	JAPAN	ITALY	GERMANY	INDIA	UK	TURKEY	AUSTRALIA	VIETNAM
6.	USA	JAPAN	FRANCE	UK	SOUTH AFRICA	GERMANY	GERMANY	GERMANY	TURKEY	AUSTRALIA
7.	CHINA	BELGIUM	AUSTRALIA	ROMANIA	FRANCE	KOREA	THAILAND	KOREA	GERMANY	SPAIN
8.	SPAIN	UK	INDIA	INDIA	KOREA	AUSTRALIA	KOREA	AUSTRALIA	MEXICO	GERMANY
9.	BELGIUM	AUSTRALIA	GREECE	GREECE	AUSTRALIA	FRANCE	AUSTRALIA	BRAZIL	KOREA	UKRAINE
10.	AUSTRALIA	GREECE	BULGARIA	AUSTRALIA	INDIA	CANADA	TURKEY	UK	NETHERLANDS	KOREA
RANKING EU	1.	1.	1.	2.	3.	3.	4.	5.	4.	2.
MARKET LEVEL TO ACCESS THE TOP 10										
	389 MW	426 MW	843 MW	792 MW	779 MW	675 MW	818 MW	944 MW	1 621 MW	3 130 MW

SOURCE IEA PVPS & OTHERS.

Other countries that installed significant amounts of PV but below the GW, are France (996 MW), Poland (804 MW), Argentina (775 MW), Italy (758 MW), Belgium (587 MW), Israel (556 MW) and finally, Kazakstan and Malaysia which are just below the 500 MW threshold.

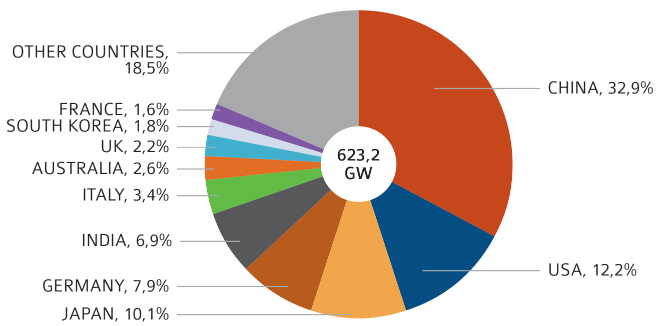
The total installed capacity in most countries takes decommissioning of PV plants into account. While such numbers remain relatively limited for the time being, they start to impact at a very low level, which can lead to discrepancies in national statistics of several IEA PVPS countries. Off-grid numbers are difficult to track and most numbers are estimates. Changes and decommissioning are higher for these applications than in other segments and can lead to number 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.

FIGURE 2.5: GLOBAL PV MARKET IN 2019



SOURCE IEA PVPS & OTHERS.

FIGURE 2.6: CUMULATIVE PV CAPACITY END 2019



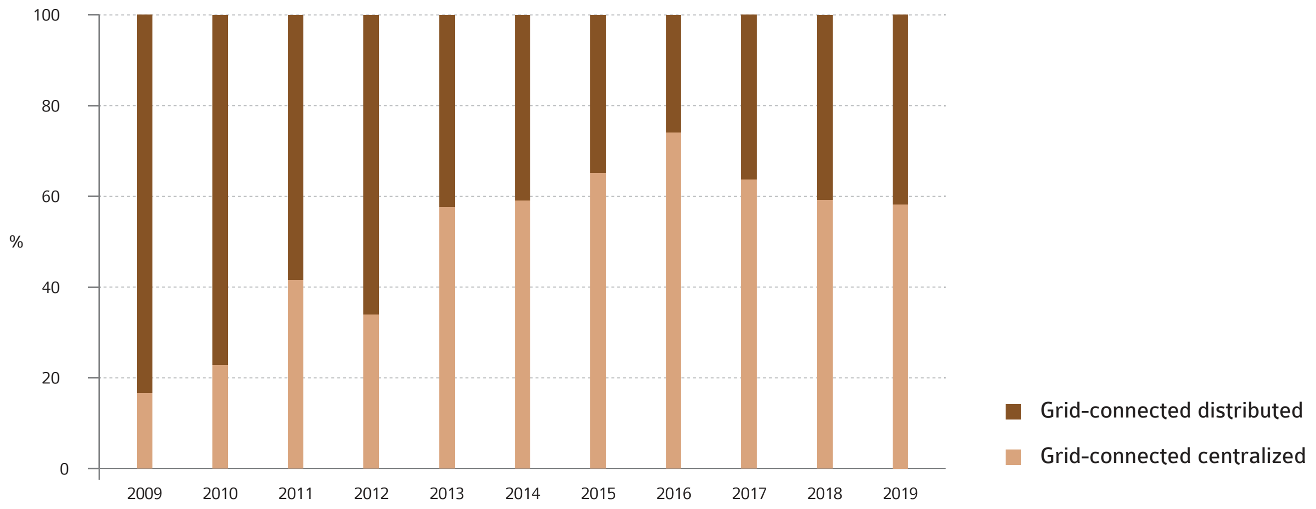
SOURCE IEA PVPS & OTHERS.

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 over large, centralized installations, should not be underestimated, utility-scale PV is likely to keep dominating electricity generation in many countries. The main reason are the economies of scale, outweighing the savings in transmission costs and the self-consumption possibilities brought by embedded installations.

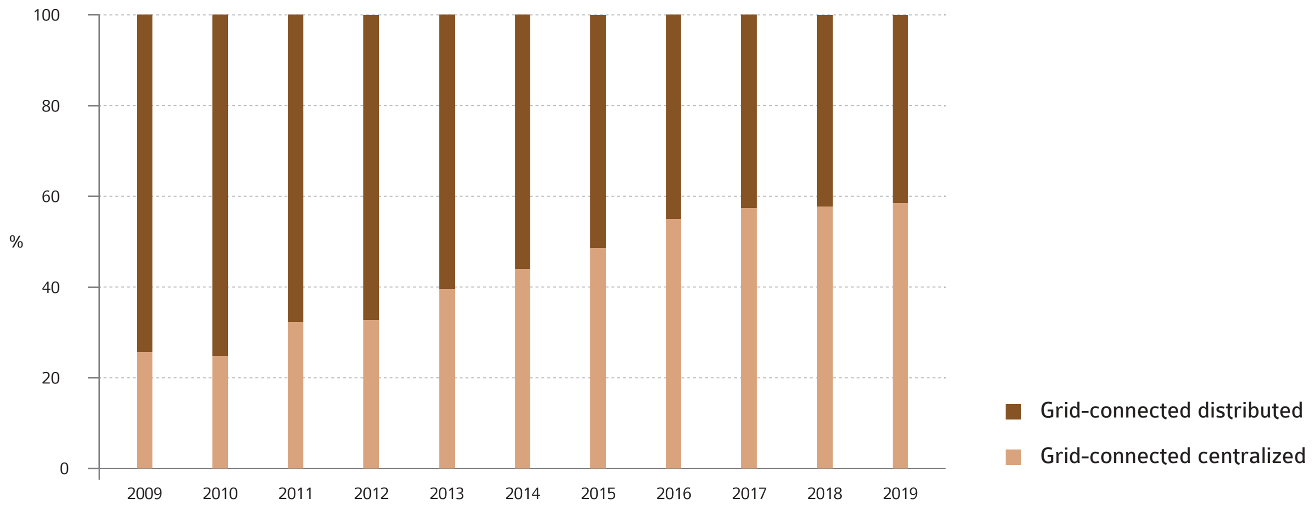
Ground mounted utility-scale PV installations increased in 2019 with more than 70,5 GW, compared to 64 GW in 2018 and 63 GW in 2017. However, the share of utility-scale still represented around 63% of cumulative installed capacity because distributed PV also grew significantly, up to 41,1 GW in 2019 compared to 36 GW in 2018. Off-grid and edge-of-the-grid applications are increasingly integrated in these two large categories.

FIGURE 2.7: ANNUAL SHARE OF CENTRALIZED AND DISTRIBUTED GRID-CONNECTED INSTALLATIONS 2009 - 2019



SOURCE IEA PVPS & OTHERS.

FIGURE 2.8: CUMULATIVE SHARE OF GRID CONNECTED PV INSTALLATIONS 2009 - 2019



SOURCE IEA PVPS & OTHERS.

PV MARKET SEGMENTS / CONTINUED

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 centers or industries, but generally they feed electricity into the grid.

Due to the simplicity of feed-in policies, 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, which trigger a significant decline in the value of PPAs and enlarge horizons for PV development. Merchant PV, where PV electricity is directly sold to electricity markets or consumers is experiencing growth in numerous countries, but this market driver remains limited so far.

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. After years when feed-in tariffs policies drove the utility-scale market, tenders are now the key regulation to unlock PV development. Amongst the countries proposing tenders, France, Germany, Greece, the Netherlands, Poland, Portugal and Spain can be mentioned in the EU, the UAE, Jordan and Oman in the Middle East, Brazil, Mexico, Guatemala and Nicaragua in Latin America, Egypt, Morocco and Tunisia in Africa, and Nepal and Sri Lanka are the newcomers in Asia. However, more and more tenders are being launched for small-scale market segments. In 2019, several European countries organized tenders for market segments from 500 kW up to 20 MW (France and Germany for instance).

Until recently, tenders offered an alternative to unsubsidised installations due to the lack of competitiveness with wholesale market prices but constrained the market, while favouring the most competitive solutions (and not always the most innovative, unless mentioned explicitly). Spain and Chile were the first markets to become attractive for utility-scale PV plants financed under merchant PV business models (wholesale market electricity sales only, possibly adding grid services), which is expected to shape differently the PV market in the coming years. The lowest PV electricity prices signal the start of a new era where merchant PV could start to compete with policy-driven PV installations.

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 are often making the distinction between the electricity consumed and the electricity injected into the grid, thereby incentivizing self-consumption. Examples of established markets moving away from net-metering are Denmark which replaced the scheme with a time window of one year calendar to two schemes with a one-hour or an instant time window and Belgium which totally or partially supressed net-metering in some regions for new installations. Vietnam has replaced the successful net-metering payment mechanism from rooftop solar projects with a direct trading scheme. However, some emerging PV markets still set up net-metering schemes as they are easier to set in place and do not require investment in complex market access or regulation for the excess PV electricity. Net-metering has been announced or implemented recently, mainly in the Middle East (Bahrain, Dubai and Lebanon) and in Latin America (Chile, Peru, Ecuador) but also in Asia (some states in India, Indonesia, Thailand, etc) and in some emerging countries in Europe (Albania, Romania and Turkey).

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. In Brazil, the distributed segment grew with 482 MW in 2018 and 1,5 GW in 2019 due to rising electricity prices. Rising electricity prices in Australia and South Africa are also responsible for the massive uptake of solar PV by residential consumers.

Overall, the main trend goes in the direction of self-consuming PV electricity in most of the 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 41 GW in 2019 after a year of market stabilization.

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 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) 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.

EMERGING PV MARKET SEGMENTS

FLOATING PV: A GROWING MARKET SEGMENT

Land is scare in many countries, certainly close to consumption hubs, where it matters even more to install PV massively and large-scale installation could play an important role, but the potential is limited. Floating PV appears to be a smart alternative: installing floating PV systems on man-made lakes, water reservoirs and even seas, allows to develop utility-scale PV without using land. By installing PV on water reservoirs, it has been shown that PV limits evaporation. Installed on the lake of a hydropower plant, it benefits from an already existing grid connection, and reduces the system cost. China has led the floating PV market until 2018 but went down in 2019 due to a change in incentives. Other Asian countries such as Korea, Japan, Singapore or Vietnam, as well as some European countries such as France, Germany, the Netherlands and others had either operational installations or research ones at the end of 2019 and more are being developed in 2020. While the total installed capacity reached 1,9 GW at the end of 2019, the development speed increased, with China leading the pace. However, the market declined in China in 2019 while the rest of the world was growing.

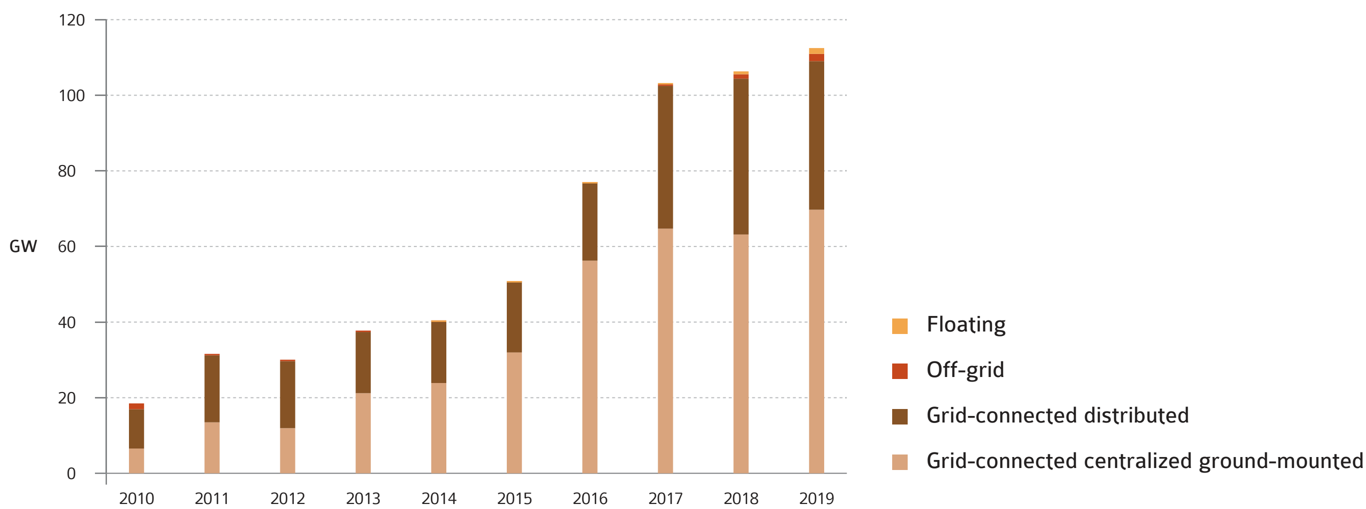
AGRI-PV: DUAL USE WHICH IS EXPECTED TO EMERGE FAST

The development of PV on agricultural land is a given but, in some cases, crops have been replaced by photovoltaics and thus the use of the land has mostly shifted towards electricity production. Agri-PV proposes a different perspective with the possibility to use PV as an additional source of revenues for farmers, complementing their agricultural business. By positioning PV systems above the crops or plants, the system can permit raising different kinds of crops with a reduced solar insulation, allowing a better development in sunny regions, and possibly new business models, such as recovering of damaged crops for instance, or different crops which would not have been profitable in some regions. This dual use imposes a different kinds of PV systems, which can in some case change their position, from horizontal to vertical and allow either maximum PV production or maximum crop production depending on the weather conditions. Defining Agri-PV could be difficult and most existing plants on agricultural land could hardly be qualified as such. We will define Agri-PV in general as a PV plant which allows a combined land use, for agriculture and for PV plants, without putting the emphasis completely on the PV plant.

BIPV: WAITING FOR THE START

The BIPV market remains a niche which can hardly been estimated properly. With multiple business models, different incentives, all kinds of buildings or infrastructures (including roads), the BIPV market cannot easily be estimated. From tiles and shingles for residential roofs to glass curtain walls and more exotic façade elements, BIPV covers different segments with different technologies. Depending on the definition considered, the BIPV market ranged from 200 MW to 300 MW per year in Europe and probably reached 1 GW globally, while the difference 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 2019. The market is also split between some industrial products

FIGURE 2.9: ANNUAL SHARE OF CENTRALIZED, DISTRIBUTED, OFF-GRID AND FLOATING INSTALLATIONS



SOURCE IEA PVPS & OTHERS.

EMERGING PV MARKET SEGMENTS / CONTINUED

such as prefabricated tiles (found in the USA and some 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. 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 most European countries, the off-grid market remains a very small one, mainly for remote sites, leisure and communication devices that deliver electricity for specific uses. Some mountain sites are equipped with PV as an alternative to bringing fuel to remote, not easily accessible places. However, this market remains quite small, with at most some MW installed per year per country. Regulations constraining self-consumption have led to residential homeowners in Portugal for instance to go for off-grid PV. However, this relates more to traditional PV grid connected systems than the usual off-grid applications. Sweden has a stable off-grid PV market mainly constituted of systems for holiday cottages, marine applications and caravans. In 2017 and 2018, about 2,06 MW and 2,03 MW respectively of off-grid applications were sold and 1,94 MW in 2019.

In Australia, a total cumulative capacity of 284 MW of off-grid systems have been installed in 2019.

Japan has reported 2 MW of new off-grid applications in 2019: bringing the installed capacity around 175 MW, mainly in the non-domestic segment.

In some countries in Asia and in Africa, off-grid systems with back-up represent an alternative to bring the grid into remote areas. 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.

Rwanda has achieved substantial results in the electrification of remote areas through the implementation of pay-as-you-go SHS. The target of the government is to bring off-grid systems to 48% of the population towards 2024.

Bangladesh installed an impressive amount of off-grid solar home systems (SHS) in recent years. An estimated 5,8 million stand-alone systems were already operational in 2019, in line with the nation’s goal of 6 million in total by 2021. Through the programme 10% of the households should gain access to electricity through SHS by 2020.

Despite its central grid dominated electrification efforts, India had foreseen up to 2 GW of off-grid installations by 2022, including twenty million solar lights in its National Solar Mission. In March 2019, the central government approved a new programme to help farmers install solar pumps and grid-connected solar power projects though pay-as-you-go models.

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.

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. The case of Greece is rather interesting in Europe, with numerous islands not connected to the mainland grid that have installed dozens of MW of PV systems in the previous years. These systems, providing electricity to some thousands of customers will require rapid adaptation of the management of these mini grids to cope with high penetrations of PV. The French West Indies have already imposed specific grid codes to PV system owners as PV production must be forecasted and announced to better plan grid management.

PV AND THE STORAGE MARKET DEVELOPMENT

Higher PV penetration levels increases the need for real time and seasonal balancing which can be achieved through storage. Storing electricity allows to integrate more renewable energy into the electricity grid and can provide other benefits as well: electricity storage can support energy management both on the demand side and on the production side, thereby reducing the use of less efficient peak power units. Furthermore, the growing competitivity of storage increasingly allows to avoid transmission and distribution infrastructure reinforcement.

Australia and the United States are the most mature markets when it comes to storage, with respectively 2,7 GWh and 1 GWh installed at the end of 2019.

Storage can be physically linked to the PV plant (solar-plus-storage system). Large-scale solar-plus-storage and projects can serve several purposes: reduced grid connection costs, reduced curtailment and delivery of grid services. Tenders for solar-plus-storage have been organized in several countries in recent years and are expected to come online soon for instance in Chad (200 MW), China (202 MW/202 MWh), Israel (168 MW), Mexico (32 MW/7 MWh), South Sudan (20 MW/35 MWh) and in the UK (500 MW).

For prosumers, the main advantage of PV in combination with storage is to increase the self-consumption of the PV installation. Storage in combination with smart energy management systems allow to shift part of the consumption when electricity prices are lower for instance. Furthermore, when the legal framework allows it, SME and residential prosumers can get access to the market to valorise this flexibility through the aggregation of their profiles.

Until recently Germany and Australia where amongst the rare nations offering rebates for residential storage systems in Germany through a limited budget for loan applications and in Australia through state government subsidies, as well as low-interest loans and demand response schemes. However, more countries are willing to incentivize the local storage of PV electricity to integrate more renewables in the grid. In Flanders, Belgium, a temporary rebate has been granted for the purchase of batteries. Batteries are incentivized through tax rebates for residential solar systems coupled with storage in Italy and commercial ones in Austria. Korea, Sweden and Switzerland are providing financial incentives for storage for residential consumers.

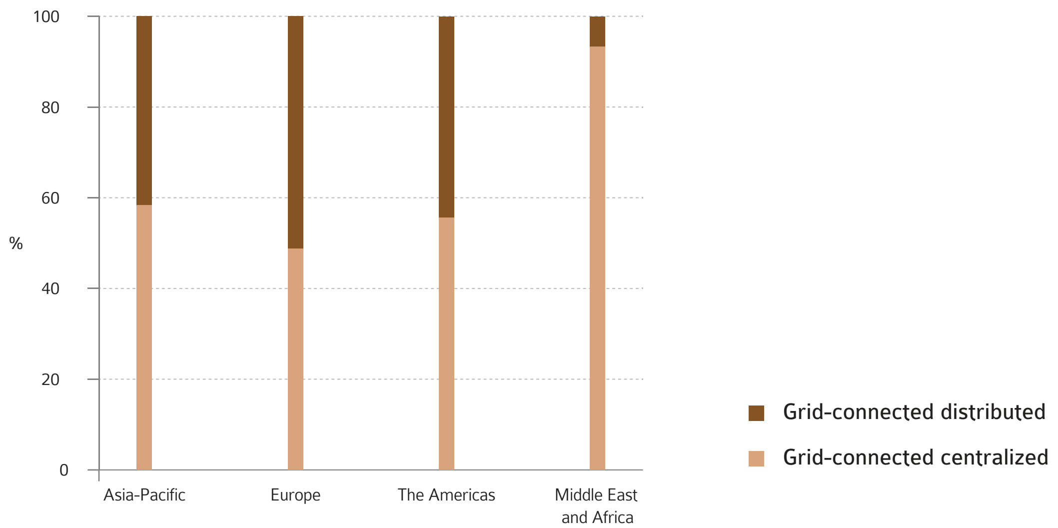
Finally, the deployment of PV technology can also work as a catalyst for other technologies with a potential to tackle climate change such as green fuels which can be used for mobility and for storage. Indeed, one key technology for the energy transition, especially when it comes to seasonal storage is probably green hydrogen production. After years of research and pilot projects, the first commercial hydrogen plants are being built all over the world.

PV PER SEGMENT

Globally, centralized PV continued to represent more than 63% of the market in 2019, mainly driven by China, the USA, and emerging PV markets. In the same trend as in previous years, 2019 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 2019, with more than 41,1 GW installed; with 17,9 GW from China alone. Remarkably, the distributed segment took off in the Middle East due to adequate policies in Israel and Jordan.

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.

FIGURE 2.10: GRID-CONNECTED CENTRALIZED AND DISTRIBUTED PV INSTALLATIONS BY REGION IN 2019



SOURCE IEA PVPS & OTHERS.

PV DEVELOPMENT PER REGION

Figure 2.11 illustrates the evolution of the grid-connected PV installations share per region from 2000 to 2019.

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 actual today, with the share of the Asia-Pacific region stabilizing around 52% in 2019, whereas the European share of the PV market went down to around 9% and came back to 18% in 2019.

The share of the PV market in the Middle East and in Africa remained stable and relatively small compared to other regions of the world up to 2019.

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.

THE AMERICAS

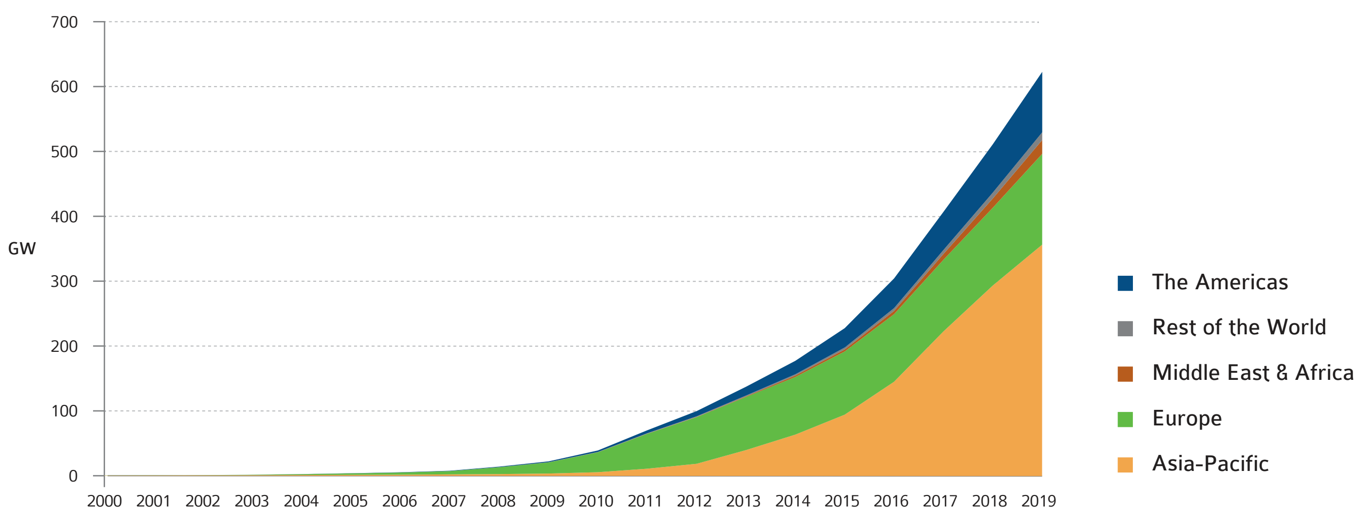
The Americas represented 25,5 GW of installations and a total cumulative capacity of 101,1 GW in 2019. If most of these capacities are installed in the USA, several countries have started to install PV in the central and southern countries of the continent: first in Chile and Honduras and more recently in Mexico and Brazil.

In a nutshell, PV is developing in the Americas mostly through tenders except in the USA. Distributed applications start to develop in several countries.

The USA's PV market fuelled the growth on the entire continent for years, while some other countries contributed marginally until the last years. Driven by a tax credit and self-consumption or net-metering policies in more than 40 states, the USA has largely contributed to the PV market development. It is the home of innovative business models for small-scale installations and competitive utility-scale installations. The market grew in 2019 and positions the USA as the key American PV market. The installations in 2019 amounted to 13,3 GW, with a total capacity of 75,8 GW.

North of the USA, Canada has averaged approximately 275 MW per year of new solar PV capacity over the past decade, over 90% of it in the province of Ontario. The vast majority of Canada's solar capacity was installed under Ontario's FIT program (2009-17), which included a local content regulation that connected the PV market development with local manufacturing. From a peak of over 750 MW installed in 2014, the market fell to a trough of approximately 100 MW in 2018, recovering somewhat last year to 232 MW, for a total estimated installed capacity of 3,3 GW.

FIGURE 2.11: EVOLUTION OF REGIONAL PV INSTALLATIONS



SOURCE IEA PVPS & OTHERS.

Mexico experienced a significant market growth with several GW of PV projects in the last years, under competitive call for tenders. The market experienced some policy difficulties in 2019 but its potential remains high given the need for new electricity sources and a dynamic economy. The installations in 2019 amounted to 1,9 GW, with a total capacity of 5,0 GW.

Chile, the most recent of the IEA PVPS country members, has installed 2,7 GW and is one of the most dynamic markets in the region. With a record irradiation level in the north of the country, utility-scale PV plants popped up rapidly at record-low production costs levels. Green hydrogen production could be the next step for this country while the harsh solar conditions in some locations could impose some technical evolution of the PV panels technology to cope with high UV conditions. Distributed generation should progress in the coming years. The new installations in 2019 amounted to 288 MW.

Outside of the IEA PVPS membership, Brazil remains the most important market: it finished the year 2019 with 4,5 GW of PV installed capacity with most of the newly installed capacity coming from distributed generation. The rooftop segments almost tripled with over 1,4 GW of new installations during 2019. Utility-scale projects represented 650 MW, a stable number compared to previous years. Several tenders were launched from 2014 until 2019 and drove approximately 2,1 GW of projects which are now connected to the grid. More than 2 GW of additional utility-scale PV projects awarded through auctions are expected to be built in the coming years. High electricity prices are driving the distributed market, which experienced a major growth in 2019.

In other countries, such as Argentina, the development is starting to take off, with 775 MW cumulative installed capacity in the country at the end of 2019 and more is expected to come online in 2020. As often it is the case, the government target of 3 GW of renewable energies (including 300 MW of PV), was beaten by the market: PV secured significantly more in the first tenders, with 916 MW allocated in 2016.

In Peru, a total of 284 MW of solar PV was installed at the end of 2019, mainly through large-scale projects awarded in tenders in 2016 and 2018. Several programmes related to rural electrification are in place for a few years and since 2018 a net-billing scheme for installations up to 200 kW has been introduced, as well as a scheme for projects up to 10 MW.

2015 was a decisive year for the PV market in Honduras with 388 MW installed. However, the following years were characterized by a reduced level of installations. The cumulative capacity installed reached 549 MW at the end of 2019. The country also invested in more than 2 700 solar home systems (SHS) to power villages, schools and municipalities.

In Colombia, around 90 MW have been installed until the end of 2019. The 2022 objectives of the government for renewables are set at 1 500 MW: to achieve this goal a first tender has been launched in 2019. In 2018, the country issued a new regulation for distributed solar generation; a net-metering scheme and the possibility to sell surplus power to the national grid were introduced.

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.

ASIA-PACIFIC

The Asia-Pacific region installed close to 58,2 GW in 2019 and are producing more than 351,2 GW in PV electricity. Mainly due to the market slowdown in China, the region experienced a significant lower growth year compared to 2018 where 70,6 GW were installed. In 2019 the region represented 52% of the global PV installations.

China remained the key market in Asia, with more than 30 GW installed and more than 200 GW cumulative capacity. The undisputed market and industry leader saw its market being reduced by one third in 2019, under pressure from new policies. However, it continues to lead the Asian and Global PV market. While utility-scale plants will be forced to improve their competitiveness towards conventional power plants, China has also developed significantly distributed PV applications. In this respect, poverty alleviation programmes have played an innovative role in supporting social policies through PV development. The so-called "Frontrunner" programme has also allowed for the promotion of high efficiency products while the industry continued growing. The industry landscape is definitively leading the pace globally, with a constant appearance of new actors, in all steps of the value chain and increased investments in new production capacities. China is poised to remain the key market and industry leader for several years.

Japan is one of the oldest PV markets and in the last decade has experienced a significant market development. With 7 GW installed in 2019 and 63,2 GW of cumulative installed capacity, the country has continued to develop PV installations in all market segments, even if the market developed faster for utility-scale plants in the last year due to commission deadlines for FIT projects. Japan is looking rapidly at VIPV as an option for increased decarbonization of the transport sector.

Australia has for some years experienced a fast and massive PV development. It initially started in rooftop applications, especially in the residential segment, and it shifted quite rapidly to utility-scale applications which are now massively developed. Australia is a perfect example of how competitive PV development is an easy task, with penetration levels which are now making the country the global number one in terms of PV capacity per capita. The decline in incentives, matched with the increasing competitiveness of PV, has had little impact on the PV market. Australia is also home of one of the key world-class research centres on PV. 4,8 GW have been installed in 2019, bringing the total capacity to 16,3 GW.

ASIA-PACIFIC / CONTINUED

Korea has experienced a fast market growth in the last two years and has installed 3,1 GW in 2019, with now 11,2 GW producing electricity. The country was for a long time one of the few using an incentive scheme based on green certificates. A large part of the market consists of utility-scale PV applications while rooftop PV represents only a small fraction of the market. The high density of population in cities can explain partially this, while some cities experienced small-scale installations, outside of any regulation. The country is home to one of the global industry leaders and is quite active on BIPV and VIPV. In 2020, the country was about to introduce CO_2-content based regulations for PV tenders.

Thailand was one of the first countries in Asia to develop PV, mainly through utility-scale plants. However, the country installed only 16 MW in 2019 and was home to 3,5 GW of PV systems at the same time. Most existing installations are utility-scale PV plants between 1 and 90 MW but the new plans unveiled by the Thai government in 2019 envisage PV deployment on rooftops, in addition to floating PV and utility-scale plants. Off-grid is developed, especially in remote areas and the countryside but remains a niche market.

Malaysia has installed 499 MW in 2019 and reached the cumulative capacity of 1,4 GW at the end of the year. The PV market in Malaysia is dominated by grid-connected PV systems. The PV market growth in Malaysia was largely driven by Large Scale Solar (LSS) and Net Energy Metering (NEM) programmes. Off-grid remains a niche market. The country hosts several large factories from foreign manufacturers and has become therefore a major place for PV manufacturing in the last years.

The PV market in India is driven by a mix of national targets and support schemes at various legislative levels. The Indian market developed in the last years but plateaued around the 10 GW mark on an annual basis. It reached close to 10,0 GWdc in 2019 due to uncertainties around trade cases, module price fluctuations and PPA renegotiations. 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. The International Solar Alliance (ISA), led by Prime Minister Modi and supported by more than 120 countries aims to install 1 000 GW in its member (emerging) countries by 2030. At the end of 2019, India had 42,9 GWdc of PV capacity.

In Vietnam, the solar market took off in 2019 with over 5,3 GWdc installed. The government has revised the FiT rates for utility-scale, rooftop and floating PV projects and should allow further growth of the utility-scale market. The positive reaction of the developers to the FiT scheme led to a massive development in 2019, far beyond the government expectations for 2020 (800 MW). The next target for 2030, 12 GW, could be reached faster than expected, while the country's electricity demand is expected to soar in the coming years.

In 2019, Taiwan installed about 1,6 GW after having installed 1 GW in 2018, it now reaches 4,3 GW of cumulative capacity. The market is supported by a FiT scheme guaranteed for 20 years. Larger systems and ground-mounted systems have to be approved in a competitive bidding process. The FiT level is higher for floating PV and the projects employing high efficiency PV modules.

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. In total, more than 325 MW were operational at the end of 2019.

In 2014, Indonesia put in place a solar policy which has been adapted in 2017 with the introduction of a cap reflecting the regional electricity supply costs. The first 50 MW of solar capacity came online in 2019 and the country's total capacity was 80 MW at the end of the year.

Pakistan is reported to have installed close to 160 MW in 2019 and it is estimated that at least 1,3 GW have been installed so far. A FiT has been introduced for utility-scale PV in 2014 and since 2015, a net-metering system exists for projects below 1 MW. 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.

After installing around 900 MW in 2016, the PV market in the Philippines decreased after the government set the due date for the FiT program, thereby creating a rush of installations in 2016. In 2019, 25 MW were installed, for a total capacity of 928 MW.

Myanmar has connected its first utility scale plant in 2019 (50 MW) and a tender has been launched for about 1 GW of large-scale solar projects. In Singapore, the total PV installed capacity was 349 MW at the end of 2019 with a target of 350 MW in 2020. Uzbekistan joined a World Bank Group programme beyond the African continent. The Government of Uzbekistan is looking to develop up to 5 GW of solar power towards 2030 and has launched several tenders to achieve that goal. In Kazakhstan, several utility scale projects of 100 MW or above were in the pipeline in 2018 amongst which 500 MW came online in 2019. In 2018, the Electricity Authority in Nepal launched tender procedures for projects ranging from 1 MW to 5 MW across 25 sites.

EUROPE

Europe has led PV development for almost a decade and represented more than 70% of the global cumulative PV market until 2012. Since 2013, 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 and others took some measures with a consequent impact on the confidence of developers and prosumers.

With an improved competitiveness and new policies, Europe doubled its market share in 2019, with 15,9 GW installed, which accounted for 18% of the global PV market. European countries had 131,3 GW of cumulative PV capacity by the end of 2019, 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 develops in Spain and Germany and could lead to a significant market share in a near future.

EUROPEAN UNION

Policy Framework

In April 2009, the first European Renewable Energy Directive went into force. Between then and the end of 2019, the total capacity of grid-connected solar photovoltaic (PV) systems in the European Union (EU28) had increased more than tenfold from 11,3 GW at the end of 2008 to over 131,3 GW at the end of 2019.

In December 2018, the recast Renewable Energy Directive (RED II) set a target of 32% renewable energy and 40% GHG emission reduction by 2030.

During the conference of parties (COP) 25 in December 2019, EU Commission president Ursula von der Leyen presented a European Green Deal, as already promised earlier in the political guidelines for the new European Commission 2019 – 2024. The EU goals spell out climate neutrality by 2050, support for companies to become world leaders in clean products and technologies as well as to ensure a just and inclusive transition. Proposals on how to finance this Green Deal were presented in January 2020 and aim to mobilise EUR 1 trillion of sustainable investments over the next decade.

In order to set a legal framework, a proposal for the European Climate Law was published in March 2020. One month later, the European Parliaments rapporteur for the Climate Law, Jytte Guteland, announced that she will back a 65% emission reduction target for 2030. This is a target, which would be in line with the UN emission gap report from November 2019.

As a response to the economic slowdown due to the COVID-19 crisis, the European Council agreed on a EUR 750 billion recovery fund on 21 July 2020. This fund is intended to set the Union firmly on the path to a sustainable and resilient recovery, creating jobs and repairing the immediate damage caused by the COVID-19 pandemic whilst supporting the Union's green and digital priorities. The Member States now must prepare national recovery and resilience plans, which have to set the individual reform and investment agenda of the Member State concerned for the years 2021-23. Eventually the budget needs to be approved by the European Parliament.

State of Play

For 2030, the Green Deal raises the bar compared with the recast of the Renewable Energy Directive (RED II) and calls for an accelerated reduction of greenhouse gas (GHG) emissions in the European Union up to 55% compared with 1990 levels.

The European Commission communication from 2018 "A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" presented nine different scenarios for achieving the decarbonisation targets by 2050. However, for the next decade all scenarios assume the same pathway with a moderate 13 to 14% increase of electricity consumption compared to 2015. The GHG emission reduction of 46% projected in all scenarios for 2030 is slightly higher than the 40% reduction target of RED II. The solar capacity of 320,5 GW considered in the above-mentioned scenarios would require PV systems with a nominal power capacity of 400 GW (concentrated solar thermal power capacity was not considered here). This is more than 10% higher compared to the approximately 360 GW needed to achieve the present 32% RES target in RED II.

At the end of 2019, the total installed PV power capacity in the EU27 and the United Kingdom had surpassed 134 GW.

Almost 60% 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 2019 when the EU27 and the United Kingdom added about 15,9 GW of new PV power capacity. Spain (4,8 GW), Germany (3,8 GW) and the Netherlands (2,4 GW) were the leading three countries. For the first time, Poland was in the top five with a newly installed PV capacity of about 800 MW. Another four countries added more than 500 MW, namely Belgium, France, Hungary, and Italy.

EUROPE / CONTINUED

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 July 2019, the Portuguese auction attracted the lowest bids. The winning projects offered electricity between EUR 14,76/MWh and EUR 31,16/MWh and have to be realised by the end of June 2022.

Spain was the leading market in 2019 with 4,8 GW installed which almost doubled the total installed capacity to 9,9 GW. This was achieved thanks to the need to reach the EU 2020 RES targets. A large part of the installations are utility-scale plants under tenders, but competitive utility-scale plants are also developing and could drive the market in the coming years. Rooftop applications under self-consumption represent some hundreds of MW.

Germany installed 3,8 GW in 2019 and has reached 49,0 GW cumulative capacity. The market is now partially driven by competitive tenders for utility-scale PV plants which supplement a dynamic self-consumption-based market for rooftop applications. Decentralized storage is vibrant and growing for small-scale applications, while competitive merchant PV starts to pop-up. German has lost the edge it had a decade ago in manufacturing but several innovative projects could bring it back on the global PV industry scene in the coming years.

The Netherlands installed 2,4 GW of PV and reached 6,9 GW of cumulative capacity at the end of the year 2019. One of the most competitive markets in Europe is largely driven by self-consumption measures, including delocalized self-consumption and some utility-scale plants. Reverse tendering has been used to allocate money to winning bidders.

France ambitiously pursues a growing market through tenders and self-consumption schemes; it installed close to 1,0 GW in 2019 and totalled 9,9 GW at the end of the year. France uses a CO_2 content rule in tenders, which could be expanded to self-consumption in 2020. BAPV remains an active market, while floating PV is gaining speed. The goal is to multiply the market by a factor of two to three in the coming years.

Belgium installed close to 587 MW in 2019 and totalled 4,9 GW cumulative capacity. Key policies are based on a local complex interpretation of self-consumption rules, which differs in the three regions composing the federal state. The rooftop market has been dynamic for years, while competitive utility-scale could start to pop-up in the coming years.

Italy installed 758 MW in 2019, a higher value than the trend of about 400 MW in recent years and totalled around 21 GW. Now, the market is driven by a new decree approved in 2019, an incentivized self-consumption scheme for plants up to 500 kW and tax credit measure (available for small size plants up to 20 kW).

Sweden saw the market rising to 291 MW in 2019 with a total capacity of 720 MW. Mostly concentrated in the residential and commercial segments, the market is driven by a mix of regulations and incentives including capital subsidies and feed-in premium. Utility-scale is marginal and off-grid installations represented a total of 16 MW at the end of the year 2019.

Despite high solar radiation, solar PV system installation in Portugal has grown very slowly until 2019. In 2019, 155 MW of PV systems were newly installed increasing the cumulative capacity to 827 MW by the end of 2019. In 2019 and 2020, two tenders resulted in extremely low bids, with the lowest at 0,011 EUR/kWh. To date, this was the most competitive bid ever, regardless of whether it can be achieved in the reality.

Austria installed 247 MW in 2019 and totalled 1,7 GW at the end of the year, with almost all installations on rooftops. The market has been largely driven by feed-in tariffs and similar incentives. BIPV installations reached 8 MW in 2019.

Denmark installed 109 MW in 2019 and had at the end of 2019 a cumulative installed capacity of 1,4 GW. The PV systems on buildings which is app. 20% of the market remains driven by the requirements in the Energy Performance Building Directive and the possibility of self-consumption. The majority 80% of the PV systems is utility scale with a PPA.

Finland installed 81 MW in 2019 and topped 214 MW at the end of the year, mostly for residential and commercial systems. Off-grid PV is widely used in remote areas.

For years, Norway was an off-grid market with little grid connected installations. The low energy prices in general left little space for PV to develop but a rooftop market is developing for some years. 51 MW were installed in 2019, almost doubling the installed capacity to almost 120 MW at the end of the year.

In Croatia, PV systems with a capacity up to 5 MW are eligible for a FiT. According to the Croatian Energy Market Operator, 53,43 MW of PV systems were installed under this scheme at the end of May 2019. Around 6 MW additional capacity was added in 2019 for a total capacity of 70 MW. In April 2019, Hrvatska Elektroprivreda announced the construction of four PV power plants with a combined capacity of 11,3 MW until April 2020. Until 2030 the company plans to increase its solar PV capacity to 350 MW.

After two years of rapid growth 2010 and 2011, Slovakia’s market fell by almost 90% with only 35 MW and 45 MW new installations in 2012 and 2013 and has since been installing around 5 MW per year. The total capacity of 570 MW is more than three and a half times the original 160 MW capacity target for 2020.

UK installed some hundreds of MW in 2019, far from the GW-scale market it used to be a few years ago. The country had more than 13 GW of PV at the end of the year 2019, with a market mostly focused on small-scale applications. PPA-driven utility-scale PV could develop in the coming years.

Poland installed 900 MW the last year and Hungary has started to develop PV rapidly, with a focus on small-scale installations. These countries came later on the market, while most neighbouring countries developed PV in the early phase.

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. Solar photovoltaic capacity should reach 1,75 GW. In 2019 about 260 MW of new PV capacity was installed in Russia, increasing the total capacity to around 1 160 MW (including ca 400 MW in Crimea).

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 2019, the cumulative capacity had exceeded 8,0 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.

In 2009, Ukraine introduced the "Green Tariff" policy, a feed-in tariff scheme for electricity generated from renewable energy sources. The scheme was modified a few times in the last years to adapt the remuneration levels. The latest change, in August 2020, introduced retroactive cuts for existing plants and compensations for curtailment. Over 3,5 GW of new PV power capacity was installed in 2019, thus increasing the total capacity to 4,9 GW (excluding the approx. 400 MW in Crimea).

MIDDLE EAST AND AFRICA

For 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 2019, around 5,0 GW have been installed in the region, representing 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. At the beginning of 2020, more than 18,4 GW was operational in the region.

Israel has installed 556 MW in 2019 and reached a total capacity of 1,9 GW at the end of 2019. The market is split between rooftop and utility-scale plants. The last tender conducted in 2020 consisted of PV-plus-storage, a trend which increases in several countries.

Morocco reached 200 MW of PV capacity at the end of 2019 with some uncertainties on the real installations. The market is split between utility-scale plants that the government would like to develop and large rooftops for private companies. Ambitions exist for further development, with less focus on solar CSP than in the recent past and local manufacturing is promoted by the authorities.

South Africa was the first major African PV market, under several tenders that led to 2,6 GW installed at the end of 2019. 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.

Egypt is the new African market leader with 1,65 GWac 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.

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 more have been announced. More than 2 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.

Due to the declining costs and the introduction of net metering policies in Israel, Jordan, Saudi Arabia and Tunisia, the region is starting to tap into its solar distributed generation potential.

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.

MIDDLE EAST AND AFRICA / CONTINUED

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, therefore the development of PV is expected to increase in the coming years mainly in 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.

TABLE 2.2: 2019 PV MARKET STATISTICS IN DETAIL

COUNTRY	2019 ANNUAL CAPACITY (MW)			2019 CUMULATIVE CAPACITY (MW)		
	DECENTRALIZED	CENTRALIZED	TOTAL	DECENTRALIZED	CENTRALIZED	TOTAL
AUSTRALIA	2 248	2 510	4 758	10 562	5 783	16 344
AUSTRIA	237	10	247	1 684	18	1 702
BELGIUM	480	107	587	4 739	122	4 861
CANADA	91	141	232	1 176	2 150	3 326
CHILE	0	288	288	20	2 674	2 694
CHINA	12 200	17 900	30 100	63 730	141 512	205 242
DENMARK	24	85	109	1 207	155	1 362
FINLAND	81	0	81	214	0	214
FRANCE	454	512	966	5 826	4 108	9 934
GERMANY	3 038	797	3 835	41 121	7 895	49 016
ISRAEL	225	331	556	749	1 165	1 914
ITALY	504	254	758	8 953	11 913	20 865
JAPAN	4 154	2 877	7 031	40 919	22 273	63 192
KOREA	145	2 985	3 130	985	10 244	11 229
MALAYSIA	85	414	499	487	930	1 417
MEXICO	230	1 696	1 926	825	4 176	5 001
MOROCCO	1	0	1	0	206	206
NETHERLANDS	844	1 508	2 352	3 137	3 737	6 874
NORWAY	51	0	51	120	0	120
PORTUGAL	100	55	155	426	401	827
SOUTH AFRICA	0	151	151	345	2 215	2 560
SPAIN	550	4 201	4 751	997	8 913	9 910
SWEDEN	277	14	291	683	37	720
SWITZERLAND	325	0	325	2 498	0	2 498
THAILAND	8	8	16	650	2 879	3 529
TURKEY	0	1 398	1 398	10	8 537	8 547
UNITED STATES	4 871	8 401	13 272	30 011	45 759	75 770
IEA PVPS	**32 222**	**46 643**	**77 865**	**222 278**	**287 594**	**509 872**
NON-IEA PVPS	**9 876**	**23 843**	**33 720**	**29 375**	**83 987**	**113 362**
TOTAL	**41 099**	**70 486**	**111 585**	**251 653**	**371 581**	**623 234**

SOURCE IEA PVPS & OTHERS.

three

POLICY FRAMEWORK

In the early development of PV, many markets have been powered by a broad spectrum of support policies, aiming at reducing the gap between PV's cost of electricity and the price of conventional electricity sources. These support schemes took various forms depending on the local specificities and evolved to accommodate with market evolutions or policy changes.

In recent years, the increased competitiveness of PV has allowed a number of market segments to develop without any form of financial support. Since the question of the competitiveness of PV is less pressing, a large part of new policies also are focussed on developing distributed PV through self-consumption schemes. In parallel, the development of utility-scale PV is starting to see the development of private contracts known as Power Purchase Agreements (PPA). However, the competitiveness of PV is not yet guaranteed in all segments and locations. Furthermore, the increased penetration of PV electricity lowers the average electricity prices. Therefore, targeted financial incentives might still be needed for some years to overcome costs or investment barriers in many countries.

Policies supporting distributed PV and self-consumption policies might be considered as non-financial incentives since they set up the regulatory environment to allow consumers to become prosumers. However, these policies require fine tuning, especially on grid costs and taxes, which in some cases could be considered as indirect financial incentives. In general, self-consumption policies as explained in detail below simplify and adapt the regulatory framework to allow PV self-consumption to develop. Several countries continue to support financially self-consumption through various schemes like "net-metering" or "net-billing" or "feed-in-premiums".

In addition to direct policies supporting PV development, other indirect policies have a tremendous effect on PV development, or on some technologies. Sustainable building requirements, for instance, will become increasingly essential to support a long-lasting PV market development.

Today, climate policies have an indirect effect but are shifting upwards the competitiveness of renewable energy sources. Some countries have indicated the willingness to significantly increase "carbon" taxes, propelling PV's competitiveness and accelerating its development.

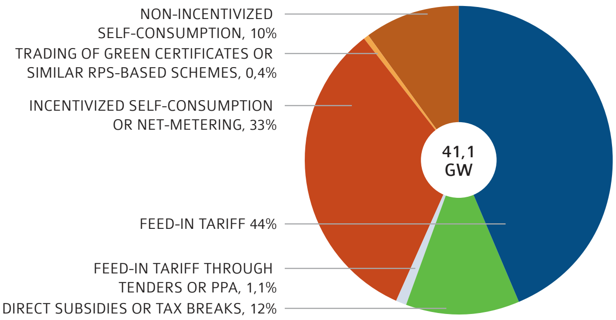
In some countries, sustainability policies are part of a push towards a cleaner industry and in particular some technologies. In addition to GHG emissions, they focus on hazardous materials, air or land pollution and more.

Grid codes and tariffs, even if not applicable to PV only, also frame the ecosystem in which PV develops, and are adding or alleviating constraints for developers and prosumers.

This chapter focuses on existing policies and how they have contributed to develop PV. It pinpoints, as well, local improvements and examines how the PV market reacted to these changes.

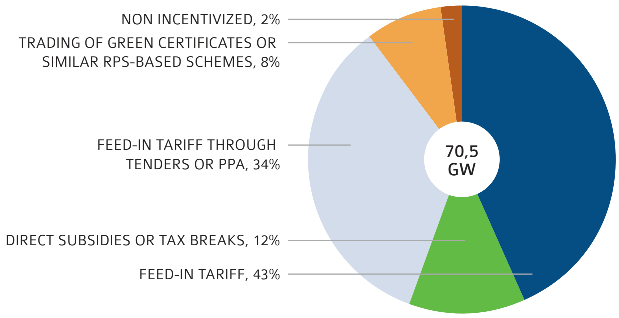
Finally, cross-sectoral aspects of PV development will also imply that PV will be submitted to additional regulations and policies, especially in the building and transport sector, but also in agriculture, the urban environment, industrial processes and more.

FIGURE 3.1A: MAIN DRIVERS OF THE DISTRIBUTED PV MARKET IN 2019



SOURCE IEA PVPS & OTHERS.

FIGURE 3.1B: MAIN DRIVERS OF THE CENTRALIZED PV MARKET IN 2019



SOURCE IEA PVPS & OTHERS.

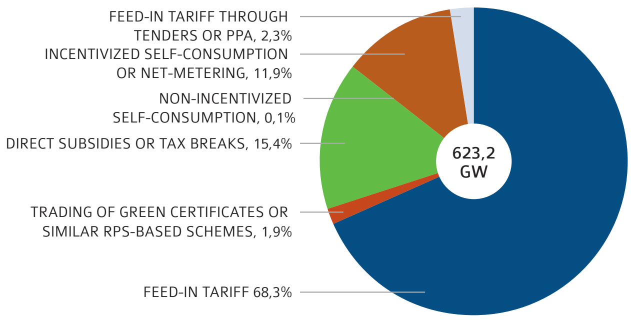
PV MARKET DRIVERS

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.

Figure 3.1a, 3.1b and 3.2 taken together shows that in 2019, around 5% of the volume of the market became independent of support schemes or adequate regulatory frameworks: this implies installations not financially supported and realized through outside of tenders or similar schemes. This is a significant improvement compared to previous years. If small-scale, distributed installations based on self-consumption were the first segment to develop, non-subsidized is gaining momentum for utility-scale PV. The trend is clear, PV plants selling their production to corporate customers have started to emerge in Spain and Chile and where followed by project developers in the Australia, Germany, USA, Denmark and, more recently, Italy and Sweden.

Around 34% of utility-scale plants were realized through tenders: this is a significant increase which started a few years ago. In comparison, tenders contributed to 1% of the distributed market, even if this number is expected to increase as more tenders are launched for rooftop projects (amongst others in Bangladesh, Bahrain, India, France, Myanmar). The sign that competitive tenders have seen their share of the global market increasing to 22% (compared to 7% before 2017) is not a major concern yet for the industry. However, as most countries are transitioning to tenders to grant PPAs and the numbers are expected to further grow in the coming years, the shrinking profit margins, especially in super-competitive tenders, could become a threat for the long-term stability of some market actors, hence creating more market concentration.

FIGURE 3.2: HISTORICAL MARKET INCENTIVES AND ENABLERS



SOURCE IEA PVPS & OTHERS.

Globally, about 44% of the PV installations are receiving a predefined tariff for part or all of their production; respectively 44% and 43% for the distributed and the centralized segments. Despite the fact that the share of the market driven by FiT has not diminished significantly through the years, there is global trend towards lower tariffs. This diminishing trend of the FiT is in line with the price decrease of the technology.

With around 12% global market share, 21% for the distributed segment and 14% of the centralized segment, direct subsidies are the third most represented form of support for PV, most of the time they cover only a part of the whole installation cost. They are by definition a constraint to PV development.

Self-consumption, supported by different mechanisms such as net-metering and net-billing, represented 33% of the distributed PV market, a threefold increase compared to historical installations. Various forms of support to self-consumption schemes exist, for example in Italy with the Scambio Sul Posto (a net-billing scheme), Israel, or Germany. Although net-metering is being abolished in historical markets, countries such as Thailand and Ecuador introduced net-metering for residential PV owners recently. Net-metering remains an easy way to activate the distributed PV market but requires shifting to self-consumption later.

Green certificates and similar schemes based on RPS represented around 5% of the market, a stable and low share which is explained by the greater complexity of this type of scheme. Green certificate trade still exists in countries such as Belgium, Norway, Romania and Sweden. Similar schemes based on RPS exist in Australia and Korea for instance.

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.

THE SUPPORT SCHEMES

FEED-IN TARIFFS INCLUDING PPA

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. 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 lower remuneration for the excess electricity injected into the grid.

Amongst the IEA PVPS members, 16 countries had a FiT implemented in 2019 (Australia, Austria, Canada, China, France, Germany, Israel, Italy, Japan, the Netherlands, Portugal, Sweden, Switzerland, Thailand, Turkey and the United States). 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 installations. However, the decision of the Chinese government to phase out FITs for PV installation by the end of 2020 is likely to influence this figure in the coming years.

National or Local

Depending on the country specifics, FiT can be defined at the national level (China, Japan, Germany, etc.) and at the regional level (Australia, Canada, India, etc.) with some regions opting for it and others not, or with different characteristics. FiT can also be granted by utilities themselves (Austria, Sweden and Switzerland), outside of the policy framework to increase customers' fidelity.

Automatic or Ad Hoc Adjustment

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 effective cost of PV systems, especially when the budget available for the FiT payments is not limited. To be sure, 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 and to a certain extent in China in 2015, 2016 and 2017, and to a lesser extend 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 only recently.

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. Germany also planned a capacity ceiling which has been removed recently to allow further development of the market. In France and Italy, the FiT decrease is dependent on both installation rates and on economic indicators. Other countries have opted for a market-based decrease strategy and adapt their FiT on a regular basis, such as Japan and, China for instance.

Tendering and Auctioning

Calls for tender 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. Since bidders must compete with one another, they tend to reduce the bidding price at 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 believe such low bids are possible with extremely low capital costs, low components costs and a reduced risk hedging. Therefore, it is conceivable that they do not represent the average PV price in all cases but are showcases for super-competitive developers.

The race to the bottom in international tenders is driving the solar power price down to the extent that project developers might start to bid at levels which speculate on further reductions in solar panel costs, and in interest rates. Certainly, tender competition has, in some countries, resulted in the emergence of dive bidding and what has been termed the "winner's curse" whereby a successful bidder underbids in order to win the contract and then cannot deliver power at the agreed-upon price. Declining investment must also be considered in the context of interest rates, which determine the cost of capital used to finance solar projects, and which constitute a significant portion of total project costs.

THE SUPPORT SCHEMES / CONTINUED

Tenders

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. This principle could also be applied to rooftop PV development.

Tenders have gained success in the entire world over the last years and Europe aligned with this trend while several countries adopted or reintroduced tenders. Several countries such as France, Germany, Greece, Poland, Portugal, Estonia and Spain introduced or reintroduced tenders for different market segments, with France using it for some market segments (above 100 kW in a simplified version and above 250 kW in all cases), while Germany is rather using it for utility-scale plants.

In the Middle East and North Africa, tenders were issued in Egypt, Israel, Jordan, Morocco, South Africa and the UAE. In the rest of the world, many others have joined the list of countries using calls for tenders to grant PPAs for PV plants. 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.

Tenders are often technology specific, however, technology neutral tenders have been introduced in Denmark, Estonia, Italy, Lithuania, the Netherlands, Poland, UK and South Africa. In this case, PV is put in competition with other generation sources. Some countries such as France, Germany and Italy are experimenting with mixed auctions based on solar and wind in parallel with some technology specific tenders.

Spain innovated with a tender based not on the energy prices or capacities, but on the level of support required. In this auction process, bidders have to offer a discount on the standard value of the initial investment of a reference plant. The lowest bid winning the tender up to a predefined capacity level is required. This tender also has the particularity to be technology neutral but welcomes only PV and wind.

Competitive tenders can be used to promote specific technologies or impose additional constraints such as local manufacturing to boost the local industry. This type of requirement has enabled the development of local solar panel manufacturing in some African countries such as Algeria, Morocco and South Africa. The FiT payment can be adjusted to some parameters. Turkey, for instance, applies a premium for local content, on the top of the normal FiT. In several countries, a local content parameter has been discussed and acts as an additional primary or secondary key in the grant decision.

In summary, FiT remains the most popular support scheme for all sizes of grid-tied PV systems; from small household rooftops applications to large utility-scale PV systems. The ease of implementation continues to make it the most used regulatory framework for PV globally.

FEED-IN PREMIUM

In several countries, the FiT schemes are being replaced by feed-in premiums. The concept behind the premium is to be paid in addition to the wholesale electricity market price. Fixed and variable premiums can be considered. In Germany 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 and Sweden is using a fixed FiP for small decentralized systems. A so-called Contract for Difference scheme is a FiP that ensures a constant remuneration by covering the difference between the expected remuneration and the electricity market price.

CORPORATE POWER PURCHASE AGREEMENTS

While FiT are paid in general by official bodies or utilities, Power Purchase Agreements (PPAs) are becoming compulsory in some countries. In Chile, for instance, the PV plants built in the northern desert of Atacama had to find PPAs with local industries in order to be beneficial (even if the low prices are now pushing for PV electricity sold into the electricity market). Such plants can be considered as competitive, since they rely on PPAs with private companies rather than official FiT schemes.

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. The reduced LCOE allows new market segments development, more recently unsubsidized PPAs also started to appear in Denmark, Germany, Italy and Sweden.

The USA and Australia are also markets were 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 with the power plant, a solution favoured more and more by large companies willing to decrease their GHG emissions.

RENEWABLE PORTFOLIO STANDARDS AND GREEN CERTIFICATES

The regulatory approach commonly referred to as "Renewable Portfolio Standard" (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 under various forms. State incentives in the USA have been driven in large part by the passage of Renewable Portfolio Standards (RPS). An RPS, also called a renewable electricity standard (RES), requires electricity suppliers to purchase or generate a targeted amount of renewable energy by a certain date. In Belgium's regions, Norway, Romania and Sweden, PV receives a specific number of these green certificates for each MWh produced. A multiplier can be used for PV, depending on the segment and size to differentiate the technology from other renewables. For example, different multipliers are applied to floating PV and PV with storage batteries in Korea. In Belgium, all three regions use the trading of green certificates for commercial and industrial segments. Romania uses a quota system, too, which however experienced a drop in the value of the green certificates in 2014. The UK was still using a system called ROC (Renewable Obligation Certificates) for large-scale PV in 2015, but it was replaced in 2016. Remarkably, Sweden and Norway share a joint, cross-border, Green Electricity Certificate system.

DIRECT SUBSIDIES AND TAX CREDITS

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 countries such as Austria, Australia, Canada, Finland, Italy, Japan, Korea, Lithuania, Norway and Sweden just to mention a few. These subsidies are, by nature, part of the government expenditures and are limited by their capacity to free up enough money.

Tax credits have been used in a large variety of countries, ranging from Belgium, Canada, Japan, France and others. Italy uses a tax credit for small size plants. The debate was intense in the USA in 2015 whether extending the ITC (Investment Tax Credit) or to phase it out rapidly. Finally, the decision was taken to continue the current scheme at least until the end of the decade.

"CARBON" TAXES

Some attempts have been made to impose carbon taxes to support the development of renewables indirectly by putting a price on the external cost of CO_2 emitting technologies. The most important regulation has been the Emission Trading System in Europe (ETS) which aims at putting a price on the ton of CO_2. So far it has failed to really incentivize the development of PV or any other renewable source because of the low carbon price that came out of the system. A Market Stability Reserve (MSR) has been introduced to reduce the surplus of emission allowances in the carbon market and to improve the EU ETS's resilience to future shocks. The EU will further reinforce this mechanism: between 2019 and 2023, the amount of allowances put in the reserve will double to 24% of the allowances in circulation and other measured could be introduced in the coming years.

Outside of Europe, Japan was amongst the first countries to adopt a carbon pricing in 2012. More recently, a national carbon-pricing plan took effect in 2018 in Canada. Although the carbon pricing framework is federal, each province and territory has implemented its own policy approach; these include both taxes and cap-and-trade mechanisms. China launched its own cap-and-trade carbon program in December 2017, the first phase of the market only covers power generation. A carbon tax also came into effect in South Africa in June 2019.

The share of global GHG emissions covered by carbon prices initiatives is now around 20%, with China and the EU as main contributors.

In general, the conclusion of an agreement during the COP21 in Paris in 2015 has signalled the start of a potential new era for carbon free technologies and the need to accelerate the transition to a carbon-free electricity system. In this respect, PV would greatly benefit from a generalized carbon price, pushing CO_2 emitting technologies out of the market.

SELF-CONSUMPTION AND NET-METERING

Given the rooftop potential, it seems logical that a part of the PV future will come from its deployment on buildings, to provide electricity locally. The declining cost of PV electricity puts it in direct competition with retail electricity provided by utilities through the grid and several countries have already adopted schemes allowing local consumption of electricity. These schemes are often referred to as self-consumption or net-metering schemes.

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 compensating electricity consumption and the PV electricity production, some compensate real energy flows, while others are compensating financial flows. While details may vary, the bases 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. These last years, countries such as Germany or Belgium introduced taxes on solar PV production for prosumers. These taxes where in most cases fought in court as they constitute a retroactive cut for existing installations and were finally delayed or retrieved.

While the self-consumption and net-metering schemes are based on an energy compensation of electricity flows, other systems exist. Italy, through its Scambio Sul Posto (net-billing scheme), attributes different prices to consumed electricity and the electricity fed into the grid. In Israel, the net-billing system works on a similar basis. One must be careful when looking at self-consumption schemes since the same vocabulary can imply different regulations depending on the case. In Canada, the provinces of Manitoba and Saskatchewan have Net Billing systems whereas every other jurisdiction has some form of Net Metering in place. The best example is in the USA, with the wording "net-metering" being used for different self-consumption schemes in different states.

THE SUPPORT SCHEMES / CONTINUED

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.

Excess PV Electricity Exported to the Grid

Traditional self-consumption systems assume that the electricity produced by a PV system should be consumed immediately or within a 10-15 minutes time frame to be compensated. The PV electricity not self-consumed is therefore injected into the grid.

Several ways to value this excess electricity exist today:

- The lowest remuneration is 0: excess PV injected on the grid electricity is not remunerated.
- Excess electricity gets the electricity market price, with or without a bonus.
- A FiT remunerates the excess electricity at a predefined price. Depending on the country, this tariff can be lower or higher than the retail price of electricity.
- Price of retail electricity (net-metering), sometimes with additional incentives or additional taxes.

A net-metering system allows such compensation to occur during a longer period, ranging from one month to several years, sometimes with the ability to transfer the surplus of consumption or production to the next month(s). In Belgium, the system exists for PV installations below 10 kW but will disappear in some regions in the coming years. In the USA, net-metering policies differ from state to state, consequently, the payoff time varies greatly. Several emerging PV countries have implemented net-metering schemes in recent years (Chile, Israel, Jordan, UAE (Dubai) and Tunisia).

PV Communities or Collective Self-Consumption

Collective self-consumption allows to share electricity between several users, in general behind the meter but also 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.

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 for All Europeans package ("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. Furthermore, the Clean Energy Package introduces energy communities into European legislation, which allow citizens to collectively organise their participation in the energy system. The European definitions provide guidelines for the implementation in the members states, however, the details concerning the perimeter and the limits to collective self-consumption for instance are being implemented at the national level.

Concerning collective consumption behind the meter, the most advanced legal frameworks have been implemented in France and the Netherlands. The "Mieterstromgesetz" or Tenant Electricity Law in Germany enables building owners to produce and sell electricity to their tenants which makes the investment more attractive. Spain and the UK have also implemented a favourable framework for collective prosumers. Other countries such as Belgium, Croatia, Italy and Portugal have introduced some definitions but are not yet fully implemented.

In the USA, community microgrids are emerging to reduce the cost of electricity consumption and provide local resilience through storage and backup power. In Australia, Community-owned Renewable Energy allows citizens to define and invest in renewable energy projects to transform their communities in some cases to zero-net emissions. In Korea, an energy self-sufficient community in Seoul city has allowed its members to reduce its energy costs through energy savings and PV installations.

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 less grid costs than prosumers at regional or national level. Such policies are tested in some countries (Austria, the Netherlands, France, Lithuania, Mexico, Switzerland, etc.). Some utilities even launched pilot projects before the regulations were officially published (as in Austria or Switzerland). In this case, innovative products are already mixing 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.

Given the complex questions that such schemes create, especially with regard to the use of the grid, the legal aspects related to compensating electricity between several meters and the innovative aspect of the scheme, it is believed decentralized self-consumption can ease the integration of PV into the energy transformation, support the development of smarter buildings and accelerate the transition to electric vehicles.

The opportunities opened 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 emerge and could develop massively under the right regulations.

COST OF SUPPORT SCHEMES

The cost of these incentives can be supported through taxpayer's money or, and this is the most common case, at least in Europe, through a specific levy on the electricity bill. In some countries, energy intensive industrials or large consumers are exempted from the levy for competitiveness reasons and to avoid carbon leakage.

In order to control the overall cost of the financial incentives, the budget available each year can be limited and, in that case, a first-come first-serve principle is applied. Most countries did not impose a yearly cap on FiT expenditures in the past, which led to fast market development in Japan, China, Germany, Italy, Spain and many others.

Some specific examples:

Australia: Solar tenders come from a mix of state governments, local governments, electricity retailers, and the Australian Renewable Energy Agency (ARENA). Each has its own process with varying funding mechanisms, the most common being PPAs for energy generation or Renewable Energy Certificates or both. In addition to state government tenders, corporations are running tenders for supply of electricity, known as Corporate PPAs.

Belgium: Green certificates have to be bought by utilities if they don't produce the required quotas of renewable electricity, which make these costs transparent. However, when PV producers are not able to sell these certificates, they are bought by the Transmission System Operator who re-invoices these to customers through their electricity bill.

Canada: Each province and territory in Canada has different policy mechanisms for supporting solar PV. Ontario's Renewable Energy Standard Offer Program (which closed to new entrants in 2008) and feed-in tariff programs (which closed to new entrants in 2016/2017) are directly funded by Ontario electricity consumers. In Alberta, eligible large-scale renewable energy generation projects (including solar PV) can generate and sell compliance credits under the province's Technology Innovation and Emissions Reduction (TIER) carbon pricing program. There are currently several different federal, provincial and municipal grant programs providing rebates for the capital cost of behind-the-meter solar PV systems; these are funded through general revenue.

China: In 2019, the price and subsidy of photovoltaic power generation continued to decline, and at the same time, the mechanism was changed. The original benchmark price was changed to a guide price, which is the upper limit of competitive allocation projects. In 2019, the guide price levels of I, II and III resource areas are 0,4 CNY/kWh, 0,45 CNY/kWh, 0,55 CNY/kWh. The subsidy level for self-consumption has dropped from 0,32 CNY/kWh to 0,10 CNY/kWh, and the subsidy level for household photovoltaics has dropped from 0,32 CNY/kWh to 0,18 CNY/kWh.

Denmark: Support measures for PV have so far mainly been financed by the so-called Public Service Obligation (PSO) administered by the state-owned TSO. The money involved was collected as a small levy on every kWh sold. Following discussions with the European Commission on the compliance of the PSO scheme with EU state aid regulations it was decided in 2016 to phase out the PSO scheme over some years and in the future use the state budget to provide the financing of eventual RE support measures.

France: Operator remuneration (through Feed-in PPA, Additional remuneration -market premium-, bonuses, etc.) is paid to operators by a designated Co-contractor (EDF, other authorised organisations or, in certain areas, local public distribution grid managers). The Co-contractor is compensated for over-costs from a dedicated account in the national budget (Energy Transition). This account is financed by a tax on petrol and its derivatives when used as an energy source for transport or heating. Over-costs are calculated based on a typical production curve weighting of monthly average daytime spot prices on the national electricity market. The estimated total cost of compensation for 2019 for photovoltaic contracts (Feed-in tariffs and premiums) is 2 961,7 MEUR.

Germany: The EEG surcharge that covers the cost of all renewable sources is paid by all electricity consumers, with an exemption for large industrial consumers. Since 2014, prosumers with systems above 10 kW are required to pay 40% of this levy on the electricity consumption coming from PV. End users must pay the value added tax (19%) on this surcharge as well. The contribution of PV is considered as small compared to wind in the last year.

Italy: 2005-2013, Feed-in Premium/Feed-in Tariff (Conto Energia): financial cap for PV of 6,7 BEUR in terms of yearly payments. 2005–today, Scambio Sul Posto mechanism, first net-metering, from 2009 net-billing: no cap. 2019-today, new RES decree, Feed-in Premium/Feed-in Tariff: capacity cap in registries and auctions. 2020-today, self-consumption bonus for energy communities. All these costs are covered by a component of the electricity tariff.

Japan: The surcharge to promote renewable energy power generation for a household was set at 2,9 JPY/kWh in April 2019 and 2,95 JPY/kWh from May 2019 to April 2020. High-volume electricity users such as manufacturers are entitled to reduce the surcharge. The amount of purchased electricity generated by PV systems under the FIT program is around 261,9 TWh as of the end of December 2019, approaching 10,3 TJPY in total.

Korea: The cost of PV incentives in Korea is mainly covered by the central and regional governments (taxpayers). Some costs are covered by the 21 RPS obligators indirectly affecting the electricity prices (Government controls the electricity price).

COST OF SUPPORT SCHEMES / CONTINUED

Malaysia: The FiT scheme is supported by the Renewable Energy (RE) fund contributed by electricity consumers. Consumers with electricity consumption of more than 300 kWh per month are obliged to contribute additional charge of 1,6% of their electricity bill to the RE fund. The RE fund is managed by the Authority to support the renewable energy developers who invest in PV, small hydro, biomass, and biogas resources to generate electricity. The NEM and LSS schemes are supported by a passthrough mechanism to the consumer tariffs.

Spain: Specific remuneration system for renewables is financed through charges in the electricity tariff. Grant subsidies and other programs such as MOVES for alternative mobility are financed at least partially with funds from the European Regional Development Fund of the EU. Local taxes exemptions are financed by the municipalities.

USA: The ITC tax break is borne by the federal budget indirectly (since the budget is not used but it represents rather a decrease of the potential income from PV development costs). Beside federal benefits, solar project developers can rely on other state and local incentives, which come in many forms, including—but not limited to—up-front rebates, performance-based incentives, state tax credits, renewable energy certificate (REC) payments, property tax exemptions, and low-interest loans. Incentives at both the federal and state levels vary by sector and by size (utility scale or distributed).

SOFT COSTS

Financial support schemes have not always succeeded in starting the deployment of PV in a country. Several examples of well-designed support systems have been proven unsuccessful because of inadequate and costly administrative barriers. Progress has been noted in most countries in the last years, with a streamlining of permit procedures, with various outcomes. The lead time could not only be an obstacle to fast PV development but also a risk of increased costs to compensate for legal and administrative costs.

Soft costs remain high in several countries, but prices have started to go down in some key markets, such as Japan or the USA. In these two markets for instance, system prices for residential systems continue to be significantly higher than prices in key European markets. While the reason could be that installers adapt to the existing incentives, it seems to be more a combination of various reasons explaining why final system prices are not converging faster in some key markets. Moreover, it seems that additional regulations in some countries tend to increase the soft costs compared to the best cases. This will have to be scrutinized in the coming years to avoid eating up the gains from components price decrease.

INNOVATIVE BUSINESS MODELS

Until recently, a large part of the PV market was based on traditional business models based on the ownership of the PV plant. For rooftop applications, it was rather obvious that the PV system owner was the owner of the building. However, 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 (such as SolarCity, Sunrun, etc.) as their main product. Since it solves many questions related to financing and operations, as well as reducing the uncertainty on the long term for the prosumer, it is possible that such services will develop in the near future, along with the necessary developments which will push up the distributed PV.

Similarly, the pay-as-you-go financial models have been very successful for 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 its needs and owns the solar kit when enough credits have been paid.

GRID INTEGRATION

With the share of PV electricity growing in the electricity system of several countries, the question of the 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 more the development of decentralized PV in the future rather than 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. In 2019, RTE, France's TSO has issued a clear assessment of the positive effect of massive PV development on generation adequacy during the morning peak while it concluded that the balancing costs for several dozen of GW of PV in the French network would have negligible costs while high-voltage grid reinforcements costs would amount to significantly less than 1 EURcent per kWh in France. Such scenarios and calculations have been done by many TSOs and show how important PV development starts to become.

GRID CODES

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 of grid code harmonisation 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 be 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 AND TAXES

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 to 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.

The opposition from utilities and in some cases grid operators grew significantly against net-metering schemes. While some argue that the benefits of PV for the grid and the utilities cover the additional costs, others are pledging in the opposite direction. In Belgium, the attempt of adding a grid tax to maintain the level of financing of grid operators was stopped by the courts and then reintroduced. While these taxes were cancelled later, they reveal a concern from grid operators who see their income model diminishing. In Germany, the debate that started in 2013 about whether prosumers should pay an additional tax was finally concluded. The EEG surcharge is paid partially on self-consumed electricity. In Israel, the net-billing system is accompanied by grid-management fees to compensate the back-up costs and the balancing costs. In general, several regulators in Europe are expected to introduce capacity-based tariffs rather than energy-based tariffs for grid costs. This could change the landscape in which PV is playing for rooftop applications and delay its competitiveness in some countries.

SUSTAINABLE BUILDING REQUIREMENTS & BIPV

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.

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. In all member states of the European Union, the new Energy Performance in Buildings Directive (EPBD) will impose to look for ways to decrease the local energy consumption in buildings, which could favour decentralized energy sources, among which PV appears to be the most developed one, from 2020 onwards.

Two concepts should be distinguished here:

- Near Zero Energy Buildings (reduced energy consumption but still a negative balance);
- Positive Energy Buildings (buildings producing more energy than what they consume).

These concepts will influence the use of PV systems on building in a progressive way now that competitiveness has improved in many countries.

BIPV support policies have been quite popular a few years ago, especially in Italy and France where they led to massive installations, with almost 5 GW of cumulative installations in these two countries. Since then, their level has been massively reduced

SUSTAINABLE BUILDING REQUIREMENTS & BIPV / CONTINUED

and few countries now apply BIPV policies with dedicated incentives outside of China, Korea and Switzerland. Past policies supported the use of conventional PV modules for simplified BIPV installations, which led to abuses and more constraints in BIPV policies. Since then, the development of more constraining BAPV policies imposes, in some cases, higher constraints to BIPV development. An example is the limit at 100 kW for non-tendered applications in France which would impose de facto on BIPV to compete with BAPV and lead in all cases to the choice of BAPV for systems above 100 kW. Since BIPV targets building surfaces, limits are defined by the surface, rather than electricity consumption choices only. This will definitively limit BIPV development in such cases in the coming years. The lack of financial incentives reduces the attractiveness of BIPV which did not benefit as BAPV did of the tremendous price decrease linked to its massive development.

ELECTRICITY STORAGE

In the current stage of development, electricity storage remains to be incentivized to develop. While some iconic actors are proposing trendy batteries, the real market remains more complex and largely uncompetitive without financial support.

Up to 2018, the market was still limited to some specific countries that have implemented specific incentives such as Australia and Germany. However, the cost of storage is pursuing its steep decline and storage is becoming more attractive in a growing number of markets. Amongst the countries that have issued laws to incentivize battery storage in PV systems to 2019, Austria and Italy have introduced a tax rebate (storage coupled with small PV plants) and some cantons in Switzerland have subsidy schemes. In region of Flanders, Belgium, a temporary rebate has been granted for the purchase of batteries.

In Germany, soft loans and capital grant covering up to 25% of the eligible solar PV panel were offered between 2016 and 2018 and the programme has been prolonged until 2020. In Sweden, the government has introduced a direct capital subsidy for energy storage owned by private households which led to a total battery capacity of 6 362 kWh installed in 2019. In the USA, several states, including California, provide rebates for qualifying distributed energy systems.

In 2017, the National Development and Reform Commission of China published the "Guidance opinion on promotion of energy storage technological and industrial development". The document called for development of power storage to promote pilot renewable energy applications, support the grid, and allow the participation of power storage in the auxiliary service market. China is a key global manufacturer of Li-Ion batteries and its electric vehicles markets is the largest in the world.

France organized several solar tenders with storage between 2011 and 2017 in its islands: Corsica (15 MW), Reunion and Mayotte (17,5 MW), Guadeloupe, French Guiana and Martinique, Saint Barthelemy and Saint Martin (17,5 MW). In 2020, a tender has been launched to provide low carbon flexibility for the grid, around two-thirds of the selected projects are based on storage, the rest on load shifting.

Japan is as well trying to increase the numbers of projects to install storage batteries but with still limited subsidies. In the past years storage batteries for residential applications were part of a subsidy program to accelerate the development of net zero energy houses.

Since 2016, Korea's government incentivizes energy storage systems (ESS) for peak-load reduction. Consumers can get maximum 50% savings in their electricity use under the current scheme. The government also provides a very attractive REC weighting factor for PV power with ESS system. It is a temporary subsidy and it will be decreased in 2020.

Some consider that storage development for PV electricity will be massively realized through electric vehicles connected to the grid during a large part of the day and therefore, will be able to store and deliver energy to consumers at a larger scale than simple batteries. This vehicle-to-grid or V2G concepts are being explored and tested in several countries, with the Netherlands, Switzerland and Japan as front-runners.

TABLE 3.1: OVERVIEW OF SUPPORT SCHEMES IN SELECTED IEA PVPS COUNTRIES

COUNTRY	DIRECT CAPITAL SUBSIDIES	TAX INCENTIVES	FEED-IN TARIFF / FEED-IN PREMIUM	NET-METERING / NET-BILLING	SELF- CONSUMPTION	COLLECTIVE & VIRTUAL SELF- CONSUMPTION	RPS / GREEN CERTIFICATES	SUSTAINABLE BUILDING REQUIREMENTS	BIPV INCENTIVES	STORAGE INCENTIVES	EV INCENTIVES
AUSTRALIA	🟢		🟢	🟢	🟢		🟠	🟢		🟢	
AUSTRIA	🟢 🟠		🟢 🟠		🟢 🟠			🟢	🟢	🟢	🟢
BELGIUM		🟢 🟠		🟢	🟢 🟠		🟠	🟢		🟢	🟢
CANADA	🟢	🟢	🟢 🟠		🟢	🟢		🟢			🟢
CHILE				🟢	🟢		🟢				
CHINA			🟢	🟢	🟢 🟠				🟢 🟠		
DENMARK			🟢 🟠		🟢			🟢			
FINLAND	🟢	🟢		🟢	🟢		🟠	🟢			🟢
FRANCE			🟢 🟠		🟢	🟢		🟢			🟢
GERMANY			🟢 🟠		🟢	🟢					🟢
ISRAEL			🟢 🟠	🟢 🟠	🟢 🟠						🟢
ITALY	🟢	🟢	🟠	🟢 🟠	🟢 🟠	🟢		🟢			
JAPAN	🟢 🟠	🟢	🟢 🟠		🟢		🟢 🟠	🟢			
KOREA	🟢	🟢		🟢			🟠	🟢		🟢	🟢
MALAYSIA				🟢 🟠	🟢 🟠						
MEXICO				🟢 🟠	🟢 🟠						
MOROCCO			🟠		🟢						
NETHERLANDS	🟢		🟢 🟠	🟢		🟢		🟢			🟢
NORWAY	🟢				🟢		🟢				🟢
PORTUGAL			🟢 🟠		🟢 🟠		🟢 🟠	🟢			
SPAIN			🟠		🟢 🟠	🟢					🟢
SWEDEN	🟢 🟠	🟢 🟠	🟢 🟠		🟢 🟠	🟢		🟢		🟢	🟢
THAILAND			🟢 🟠		🟢						
SWITZERLAND	🟢 🟠	🟢	🟢 🟠		🟢 🟠	🟢	🟢 🟠	🟢	🟢 🟠	🟢	
TURKEY			🟢 🟠	🟢	🟢						
USA		🟠		🟢	🟢 🟠	🟢	🟢 🟠				🟢

🟢 Distributed PV applications

🟠 Centralized PV applications

SOURCE IEA PVPS & OTHERS.

four

TRENDS IN THE PV INDUSTRY

This chapter provides an overview of the evolution of the PV manufacturing industry during 2019. It is mainly about the upstream sector. So, it deals with the production of PV materials (feedstock, ingots, blocks/bricks and wafers), PV cells, PV modules and balance-of-system (BOS) components (inverters, mounting structures, charge regulators, storage batteries, appliances, etc.). The downstream sector is also briefly presented, including both project development, Operation and Maintenance (O&M). More detailed information about the PV industry corresponding to each IEA PVPS member country can be found in the relevant National Survey Reports.

While the global installed PV capacity increased to 115 GW in 2019, the production and production capacity of polysilicon, ingots, wafers, PV cells and modules increased at a higher pace than the growth of the installed capacity, as in 2018 . China has remained the world's largest producer and consumer of PV cells and modules. The trends of the Chinese PV market have played significant roles on the global PV supply and demand. The gap between the demand and the production capacity has contributed to further price reductions across the PV value chain from polysilicon to PV modules. The price competitions and thinner margins continue to drive the consolidation of the industry's upstream sector.

Major PV manufacturers have continued to invest in new technologies and the enhancement of production capacities. 2019 is the first year in which the share of single crystalline silicon (sc-Si, also known as mono-crystalline silicon) has surpassed that of multicrystalline silicon (mc-Si). The cause comes from an increase in the demand for higher conversion efficiencies and higher outputs. Major companies commercialized >500 W or >600 W PV modules using various technologies, including larger wafer sizes.

The price of PV modules (spot price of mc-Si PV module) has not significantly changed throughout 2019, going down to 21,5 USD cents/W at the end of the year compared to 22 USD cents/W at the beginning of the year. This has contributed to the reduction of initial capital costs for the installation of PV systems, as well as the LCOE. However, suppliers of PV modules continue investing in increasing their manufacturing capacity with new technologies. The current level of revenue structure seems to further accelerate the consolidation of the upstream sector. PV module manufactures need to shift from "competition of manufacturing cost and lower price" to "competition of performance and reliability".

As in previous years, trade conflicts have impacted the location of production sites. An increase in PV module production volume and capacity was reported in 2019 in the USA, which has implemented safeguard measures.

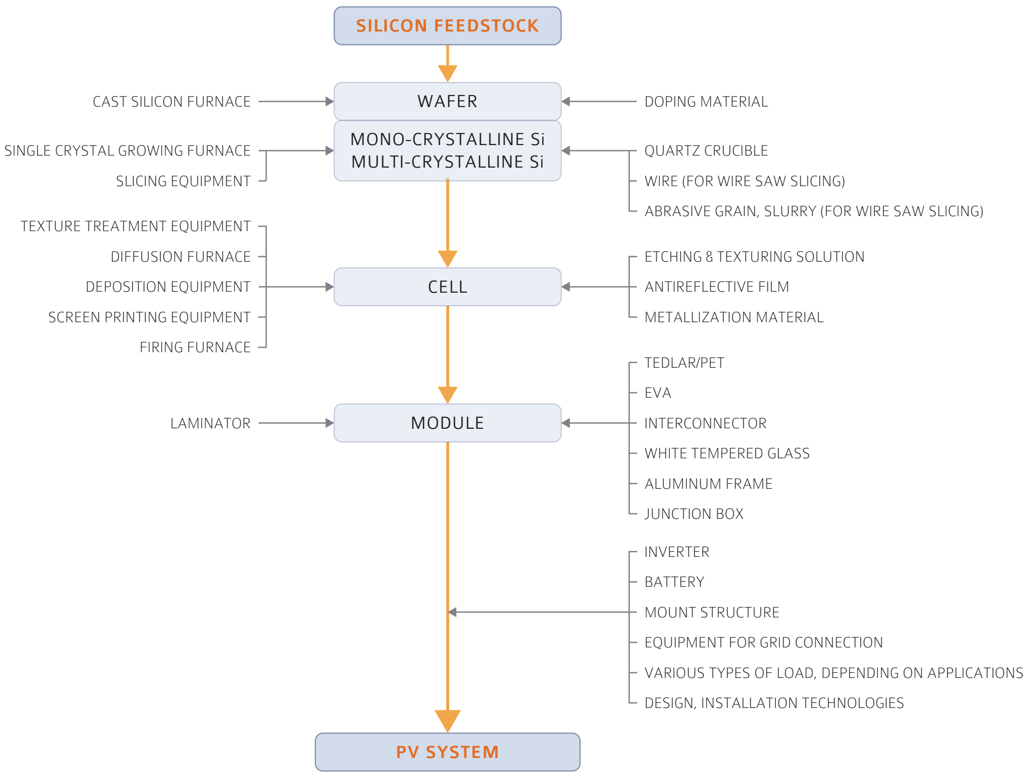
THE UPSTREAM PV SECTOR

This section reviews some trends in the value chain of crystalline silicon (c-Si) and thin-film PV technologies. While a PV system consists of various manufacturing processes and materials as shown in Figure 4.1, this section focuses on the key trends of polysilicon, ingot/wafer/cells and PV modules (c-Si and thin-film PV).

POLYSILICON PRODUCTION

The wafer-based c-Si technology dominates the PV cells production. In that respect, this section focuses on the wafer-based production path. Although some IEA PVPS countries reported the production of feedstock, ingots and wafers, the figures from the

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



SOURCE IEA PVPS & OTHERS.

National Survey Reports corresponding to the PV industry supply chain are not always complete. In such cases, external sources have been used to fill out the missing information.

The global polysilicon production (including semiconductor grade polysilicon) in 2019 was 507 500 tonnes. The polysilicon production for solar cells increased to approx. 469 000 tonnes in 2019, up by 23 000 tonnes from 446 000 tonnes in 2018. The polysilicon production for semiconductors increased from approx. 34 000 tonnes in 2018 to approx. 38 500 tonnes in 2019. The production volume of polysilicon for solar cells accounted for about 92,4% of the total production of polysilicon in 2019.

An increase in the global polysilicon production capacity was observed in 2019, as in the previous year. At the end of 2019, the global polysilicon production capacity was 712 000 tonnes/year with new additions of about 73 000 tonnes/year compared to the end of 2018 (638 999 tonnes/year). The total production capacity of six major Tier 1[2] manufacturers in 2019 amounted to about 334 000 tonnes/year, up from 333 000 tonnes/year in 2018. This accounts for about 47% of the global production capacity. As the investment to enhance production capacity continues, the total global production capacity is expected to reach 799 000 tonnes/year by the end of 2020.

Thanks to the improvement of the conversion efficiency of PV cells and modules and the efforts to reduce the use of silicon, as for example by wafer thinning; the amount of polysilicon used for 1 W of wafer (consumption unit of polysilicon) has been decreasing year after year. It is estimated that an average of 3,9 g/W of polysilicon were used for a solar cell in 2018. It decreased to an average of 3,2 g/W in 2019. Compared to the 6,8 g/W which were required in 2010, the consumption unit of polysilicon decreased at a pace of 8% annually.

The spot price of polysilicon varies depending on the market developments, basically in accordance with purity, 9N for mc-Si and 11N for sc-Si solar cells. At the beginning of 2019, 9N polysilicon spot price was 9 USD/kg level, and it kept decreasing throughout the year due to a drop in demand for mc-Si wafers. At the end of December 2019, 9N polysilicon and 11N polysilicon dropped to 7,18 USD/kg and 8,58 USD/kg, respectively.

In the first half of year 2020, the polysilicon price continued to decrease due to the stagnation of the PV market caused by COVID-19. The reported spot price of polysilicon, as of the end of June 2020, was 6,19 USD/kg. In July, two polysilicon plants in

2 Bloomberg New Energy Finance (BNEF) defines Tier 1 module manufacturers as those which have provided own-brand, own-manufacture products to six different projects, which have been financed non-recourse by six different (non-development) banks, in the past two years.

THE UPSTREAM PV SECTOR / CONTINUED

China stopped production due to fire accidents. Another polysilicon plant in China also stopped production due to failures of electricity facilities caused by heavy rain. The temporary price increase of polysilicon was observed in the 3Q 2020. How long this situation will continue remains to be seen. However, it is assumed that the price would bounce back with the recovery and the addition of new production capacity.

Most of the major polysilicon manufacturers implement the Siemens process, which is a technology developed for the semiconductor industry. Some companies adopt the fluidized bed reactor process (FZB) to manufacture granular polysilicon. The production efficiency has improved and the reported energy consumption of the reduction process is 50 kWh/kg. The slight increase of 1kWh/kg from the energy consumption in 2018, which was 49 kWh/kg, is caused by this year's higher demand of high purity polysilicon for sc-Si. An energy consumption below 40 kWh/kg has been reported by reduction processes applying advanced technologies. The energy consumption of the whole polysilicon production process decreased from 71 kWh/kg in 2018 to 70 kWh/kg in 2019. The decrease in electricity consumption related to the reduction process has been achieved thanks to the following efforts: 1) the development and commercialization of large-scale reduction furnaces; 2) the improvement of the furnace's inner wall materials; 3) the replacement of conventional silicon tube with silicon core and 4) an adjustment of gas mixtures. It is claimed that electricity consumption can be further reduced by optimizing the process and by the economy of scale, this should contribute to the reduction of polysilicon price.

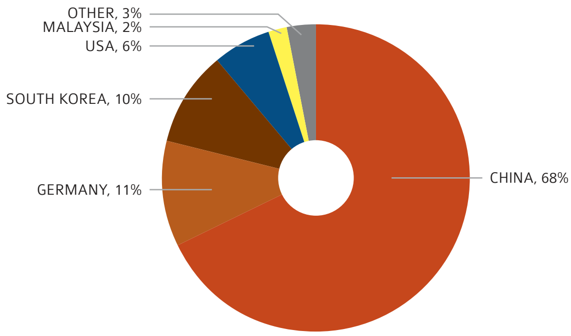
The FBR process requires less electricity than the Siemens process and produces granular polysilicon that can be efficiently packed in the crucibles with polysilicon blocks. Some manufacturers reported their efforts on the production of granular silicon due to its cost advantage. In 2019, an improvement of the polysilicon purity produced by the FBR process was reported.

In 2019 the demand for sc-Si increased, boosting the demand for higher purity products. We expect to see a higher share of higher purity products. Some manufacturers reported that around 90% of their production was oriented for sc-Si. Polysilicon manufacturers, which were mainly focused on solar-grade polysilicon, pushed by the low-price level and the thinner margins in the industry, are seeking to enter the semiconductor grade polysilicon market for higher profits.

As in the previous year, in 2019 the major solar-grade polysilicon producing countries, among IEA PVPS countries, were China, South Korea, Germany, USA, Malaysia and Norway. China continued to be the largest producer and consumer of polysilicon in the world. Figure 4.2 shows the share of polysilicon production by country.

China reported that its manufacturing capacity increased to 452 000 tonnes/year in 2019 from 388 000 tonnes/year in 2018 and produced 344 673 tonnes in 2019, accounting for 68% of the global production. In China, top six companies, GCL Poly, Tongwei, TBEA, Daqo, East Hope and Asia Silicon account for 84% of production and an oligopoly was more visible in 2019. China's imports of polysilicon decreased with a similar trend as the previous year. Most of the imports were from South Korea, Germany and Malaysia. The second largest polysilicon producing country is Germany, followed by South Korea.

FIGURE 4.2: SHARE OF PV POLYSILICON PRODUCTION IN 2019



SOURCE IEA PVPS, RTS CORPORATION.

Germany has a domestic polysilicon production capacity of over 60 000 tonnes/year. Wacker Chemie possesses a production capacity of 60 000 tonnes/year in Germany and 80 000 tonnes/year globally, including the US factory in Tennessee, USA. Wacker shipped about 58 000 tonnes of polysilicon in 2019, a slight drop from 60 000 tonnes of 2018.

South Korea reported 82 000 tonnes/year of polysilicon production capacity in 2019. The country's largest polysilicon manufacturer OCI acquired the Malaysian polysilicon factory (27 000 tonnes/year) from Tokuyama (Japan) in May 2017 and almost doubled its Malaysian production capacity from 13 800 tonnes/year to 27 000 tonnes/year. It is estimated that the company produced some 52 000 tonnes of polysilicon in 2019. The lower polysilicon price affected the business of South Korean companies. In February 2020, OCI announced to stop production of solar-grade polysilicon in South Korea and focus on semiconductor-grade product while continuing to produce solar-grade polysilicon in Malaysia in February 2020. Hanwha Solutions also decided to withdraw from polysilicon production in February 2020.

In the USA, major polysilicon manufacturers are Hemlock Semiconductor, REC Silicon and Wacker Chemie. In 2019, the USA had a 34 000 tonnes/year of polysilicon production capacity including the Tennessee Factory of Wacker Chemie. However, the polysilicon production in the USA is on a decreasing trend due to the 57% anti-dumping duties (AD) imposed on the US made polysilicon by China. Accordingly, in May 2019, REC Silicon announced that it would temporarily stop production of FBR-based polysilicon at its Moses Lake Factory in Washington, USA.

Canada, USA and Norway reported activities of polysilicon manufacturers adopting metallurgical process aiming at lowering the production cost. Silicor Materials (USA) owns a factory in Canada and is reportedly building a manufacturing factory in Iceland. Elkem Solar in Norway is estimated to have produced approx. 6 500 tonnes of polysilicon in 2019.

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. There are two types of conventional silicon ingots: sc-Si ingots and mc-Si ingots. The first type is also produced for microelectronics applications, although with different specifications depending on the purity and specific dopants; while mc-Si ingots are only used in the PV industry.

Ingot manufacturers are, in many cases, also wafer manufacturers. In addition to major ingot/wafer manufacturers, some PV cell/module manufacturers also partly manufacture silicon ingots and wafers for their in-house uses. 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.

It is estimated that about 142 GW of c-Si wafers were produced in 2019. It was an increase of 23,5% compared to 2018 with 115 GW. The wafer production capacity as of 2019 is estimated to be about 185 GW/year, a 19% increase compared to 2018 with 156 GW/year. As for wafers, major manufacturers announced the continuation of the enhancement of their production capacities. By the end of 2020, the global production capacity may exceed 200 GW/year.

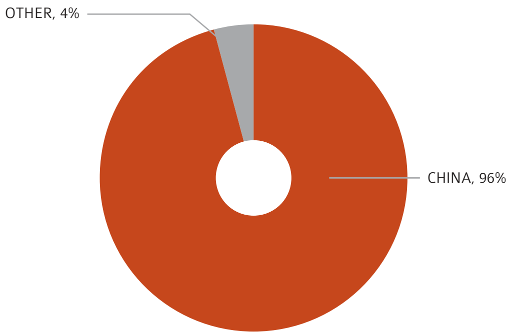
It is notable that, due to the demand for higher efficiency PV modules, the production capacity and the volume for mc-Si wafers decreased while they increased for sc-Si wafers.

As shown in Figure 4.3, China has more than 95% of the global production share of wafers. According to a report by the Silicon Branch of the China Nonferrous Metals Industry Association, the wafer production in China in 2019 was 136 GW. As previously mentioned, a shift to sc-Si technology was observed in China. In 2018, the share of mc-Si in total wafer production was 41% and it dropped to 27% in 2019. According to the China Photovoltaic Industry Association (CPIA), sc-Si wafers will account for more than 80% of c-Si wafers produced in China.

As for other IEA PVPS member countries, production capacities in South Korea and Japan remain small compared to China. Malaysia, Norway and the USA also reported ingot/wafer production activities. Besides IEA PVPS member countries, Taiwan is a major manufacturer of wafers for solar cells with about 10 companies including PV module manufacturers producing wafers, and the total production capacity is over 6,5 GW/year. In Singapore, REC Solar of Norway owns the production capacity of about 1 GW/year.

The spot price of c-Si wafer decreased further in 2019, following three factors: the price reduction of polysilicon; the cost reduction by the introducing diamond wire saws; as well as the strategic price reduction by major manufacturers. At the beginning of 2019, the price of mc-Si and sc-Si wafers were 0,274 USD/wafer and 0,39 USD/wafer, respectively. The price reduction of mc-Si wafers was significant due to the slowing demand. The price gap between the two technologies widened throughout the year. In December 2019, spot price of mc-Si wafer was 0,183 USD/wafer while sc-Si wafer price level was 0,369 USD/wafer.

FIGURE 4.3: SHARE OF PV WAFERS PRODUCTION IN 2019



SOURCE IEA PVPS, RTS CORPORATION.

In 2019, the global shares of sc-Si wafer and mc-Si wafer were 35,5% and 64,5%, respectively.

In 2019, it was notable that larger sized wafers were adopted for higher output PV modules. For sc-Si wafers, the conventional size of 6 inch (156 mm x 156 mm, also called M0) wafers has been replaced by 156,75 mm x 156,75 mm size (also called M2). In 2019, M2 products account for 61% of the wafer production. Several wafer sizes are used in 2019 for solar cell production:

- 158, 75 mm x 158,75 mm (G1),
- 163,75 mm x 163,75 mm,
- 166 mm x 166 mm (M6),
- 182 mm x 182 mm (M10), and
- 210 mm x 210 mm (M12).

According to CPIA, the share of the 158,75 mm x 158,75mm (G1) or larger sized wafers will be increased in 2020 and later. In the first half of 2020, it is reported that the G1 wafers account for more than 50% of the production in China. The commercialization or prototype manufacturing of PV modules using M12 wafers started in 2019. The adoption of larger wafer sizes for the cell and module production remains an open topic requiring a close observation. There are issues such as failures caused by mechanical wafer strength, logistics of large sized PV modules and heavier weight for handling. Standardization is also required for the further cost reduction in PV cell and module production processes. In July 2020, seven major companies such as JA Solar, JinkoSolar and Longi proposed to use M10 wafers as a standard size.

In 2019, Ga-doped wafers attracted attention as a solution for light induced degradation (LID) caused by B-O (boron-oxide) complex. Ga-doped wafers can reduce the degradation ratio of PV modules and offer better warranty conditions. Several PV manufacturers adopted this technology. Thus, it is expected that the share of Ga-doped wafers will increase in the future.

THE UPSTREAM PV SECTOR / CONTINUED

Several activities were reported in 2019 outside of China, although with a smaller the production scale. In **Norway**, NorSun announced the expansion of its n-type sc-Si wafer production capacity from 450 MW/year to 1 GW/year. In **Spain**, Aurinka Photovoltaic announced the start-up of their wafer production by the end of 2020. In **Turkey**, Kalyon Solar Technologies established a PV manufacturing plant including the wafer process with 500 MW/year. In **India**, wafer manufacturing is planned by several companies as a part of their PV manufacturing plans, combined with the utility scale projects rights.

Startup companies in the **USA** and **Europe** are developing kerfless technologies to manufacture wafers without using conventional ingot growth or wire-sawing processes. 1366 Technologies (USA) announced in February 2019 that the company will establish a mass production factory in Cyberjaya, Malaysia, to manufacture wafers by applying direct wafer technology, which directly processes wafers from molten polysilicon, in partnership with Hanwha Q CELLS (**Korea**) and Hanwha Q CELLS Malaysia (**Malaysia**). 1366 technologies announced that it achieved 20,3% of conversion efficiency with a PERC solar cell using its kerfless wafers directly processed from molten polysilicon. In December 2019, 1366 Technologies raised 18 million USD. Other companies working on new technologies are Leading Edge Crystal Technologies (**USA**), Crystal Solar (USA), and NexWafe (**Germany**).

SOLAR CELL AND MODULE PRODUCTION

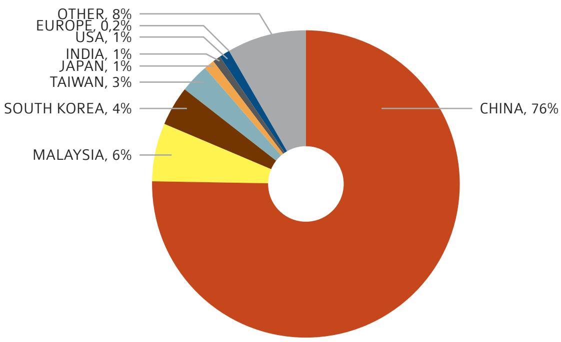
The global solar cell (c-Si and thin-film solar cell) production in 2019 is estimated at around 144 GW, that is a 14% increase from 2018 (116 GW). **China** produced 110 GW of solar cells in 2019, a 29% increase from the previous year (85 GW in 2018), maintaining its position as the world's largest solar cells manufacturer. China has been expanding its production capacity. Its solar cell production capacity was about 164 GW/year in 2019.

As shown in Figure 4.4, China's solar cell production volume accounts for 76,5% of the total global production. The global solar cell production capacity reached 221 GW/year, particularly thanks to the enhancement of production capacity in China. According to CPIA, China has more than 20 companies with a capacity above 2 GW/year.

The countries besides China which reported production of solar cells are **Malaysia**, **South Korea**, **Japan**, **India**, **USA**, and **Thailand**. Malaysia has approx. 12 GW/year of solar cell production capacity and produced nearly 8,8 GW of solar cells (c-Si and CdTe thin-film). Major PV manufacturers including JinkoSolar (China), LONGi Green Energy Technology (China), Hanwha Q CELLS (Korea), JA Solar (China), SunPower (USA), and First Solar (USA) have factories in Malaysia. About 6,3 GW of solar cells were produced in South Korea. In the USA, solar cell production is mainly conducted by First Solar with CdTe thin-film PV technology. Major non-IEA PVPS countries manufacturing solar cells are **Taiwan**, **Philippines**, **Singapore**, **India**, and **Vietnam**. However, the production capacity of Taiwan, which ranks second in production volume following China, is about 13 GW/year level, which indicates that China's presence is further increasing both in terms of production capacity and production volume. **Thailand** and **Vietnam** are not subject to the safeguard tariffs by the USA and the production capacities are increasing in these countries. As of 2019, Thailand and Vietnam have the solar cell production capacity of 2,6 GW/year and over 5 GW/year, respectively.

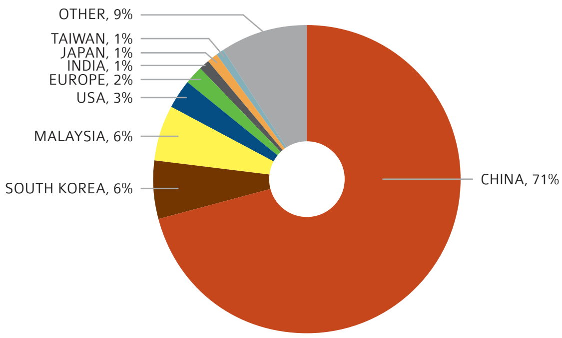
The demand for high-efficiency solar cells increases continuously, as for c-Si solar cells. In 2019, the share of PERC technology reached more than 65% in c-Si technology while the conventional BSF technology share dropped to 31,5%. The efficiency of PERC products has improved. In the first half of 2020, reported average efficiency of mc-Si PERC cells using black silicon and sc-Si PERC cell are 20,6% and 22,4 to 22,5%.

FIGURE 4.4: SHARE OF PV CELLS PRODUCTION IN 2019



SOURCE IEA PVPS, RTS CORPORATION.

FIGURE 4.5: SHARE OF PV MODULES PRODUCTION IN 2019



SOURCE IEA PVPS, RTS CORPORATION.

The share of mc-Si solar cells decreased from about 54% in 2018 to 35% in 2019. Major manufacturers are working on the commercialization of higher efficiency technologies such as heterojunction, n-type silicon PERT and TopCon, in order to respond to the demand for PV modules with higher outputs. The production capacity of heterojunction (HJT) solar cells is increasing globally. In 2019, more than 10 companies entered the HJT solar cell manufacturing field.

Major PV module manufacturers have continued making investments to improve conversion efficiencies, through efforts such as the improvement of the passivation process for PERC or PERT structures, thinning of the electrode, adoption of four or more busbars (four busbars are the standard, and five/ six-busbar products are also on sale), as well as the adoption of multi-busbar wiring or wiring without busbars.

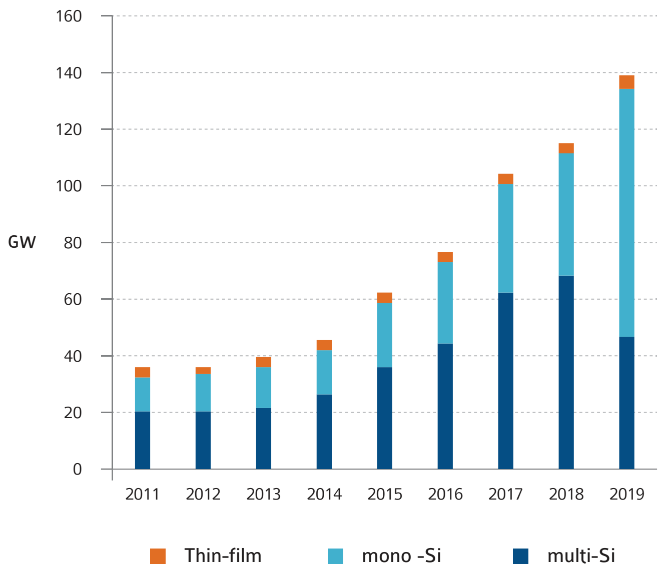
Global PV module production (c-Si PV module and thin-film PV module) increased from 116 GW in 2018 to 140 GW in 2019. As shown in Figure 4.5, China remains the largest producer of PV modules in the world, as in 2018. China produced 98,6 GW of PV modules in 2019, accounting for 70% of the total global PV module production. As of the end of 2019, China has a PV module production capacity of around 150 GW/year.

The second largest PV module manufacturing country is South Korea, which produced about 8,4 GW. Malaysia ranked third with about 8 GW of production. Other major IEA PVPS countries owning PV module production capacities are Japan, Germany and USA. Australia, Austria, Belgium, Canada, Mexico, Denmark, France, Italy, Finland, Sweden, Thailand, Turkey and South Africa also possess PV module production capacity. Among these countries, USA reported an increase of manufacturing capacity of PV modules. In 2019, the US production of PV modules was 3,84 GW, a 154% increase from 2018 (1,51 GW). Several major PV module manufactures established US factories to avoid safeguard duties imposed in 2018. Among non-IEA PVPS members, major countries producing PV modules are Singapore, Taiwan, Vietnam, India and Poland. Production bases have been established in Russia, Algeria, Brazil, Morocco, Ghana, Saudi Arabia, Indonesia and so on. As for solar cells, the production capacity of PV modules is increasing in Vietnam due to the impacts of the trade conflicts. It was reported that Vietnam has more than 7 GW/year of PV module production capacity.

India has an effective PV module production capacity of 6 GW/year. The Indian government conducts tenders for PV projects which include the establishment of local manufacturing facilities, in order to cultivate domestic industries. A similar tender was also conducted in Turkey. In addition to the requests for lowering transportation costs following the PV module price declines, there are some countries such as France and South Korea, where PV module carbon footprints are included in the requirements for support measures. It is assumed that more production bases will be established in the areas adjacent to the locations where PV markets are established.

Figure 4.6 shows PV module production per technology. Crystalline Si PV modules accounted for 96% of the global PV module production in 2019, staying at the same level as the previous year. Among the c-Si PV modules, sc-Si PV modules took the higher share (62%) than the mc-Si PV modules (34%). This was driven by the trending search for higher conversion efficiency in the market, the increase in the supply and the price reduction of sc-Si wafers. As for thin-film PV modules, the increased production of CdTe PV modules by First Solar (USA) increased the share of thin-film modules from 2,4% in 2018 to 4,0%.

FIGURE 4.6: PV MODULE PRODUCTION PER TECHNOLOGY IN 2019



SOURCE IEA PVPS, RTS CORPORATION.

THE UPSTREAM PV SECTOR / CONTINUED

TABLE 4.1: GLOBAL TOP FIVE MANUFACTURERS IN TERMS OF PV CELL/MODULE PRODUCTION AND SHIPMENT VOLUME (2019)

RANK	SOLAR CELL PRODUCTION (GW)		PV MODULE PRODUCTION (GW)		PV MODULE SHIPMENT (GW)	
1	Tongwei Solar	13,4	JinkoSolar	12,0	JinkoSolar	14,3
2	JA Solar Technology	9,2	JA Solar	10,6	JA Solar	10,3
3	LONGi Green Energy Technology	8,4	Hanwha Solutions	9,3	Trina Solar	10,0
4	Hanwha Solutions	7,1	Canadian Solar	9,0	Canadian Solar	8,6
5	Shanghai Aiko Solar Energy	7,0	LONGi Green Energy Technology	8,9	LONGi Green Energy Technology	8,4

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

SOURCE IEA PVPS AND RTS CORPORATION, ESTIMATED.

Table 4.1 shows the global top five manufacturers in terms of the PV cell/module production and the shipment volume. All of them are c-Si PV manufacturers. As for solar cells, Tongwei Solar of China, who focuses on solar cell production, ranked first with a production of 13,4 GW in 2019. The top five manufacturers of PV modules were the same as 2018. JinkoSolar has ranked first during four years in a row, with a production volume of 12 GW. These major manufacturers plan to further increase their production capacity forward in 2020. So, it is highly likely that a manufacturer with 20 GW/year shipment will appear. Furthermore, with the new enhancement of production facilities by some manufacturers, oversupply and selection of manufacturers are expected as well.

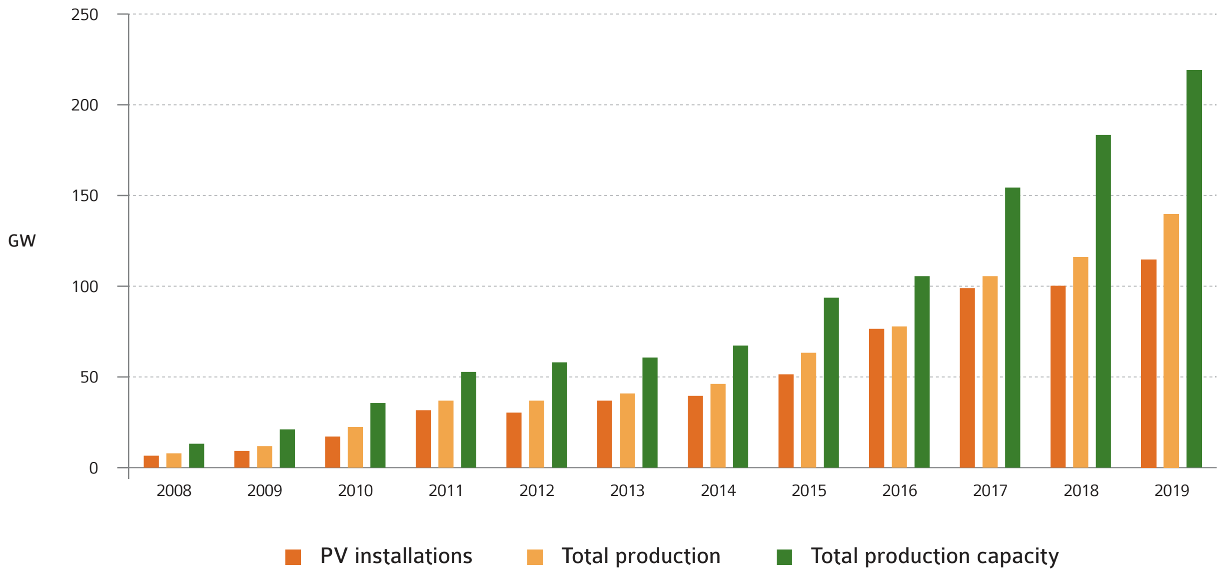
In the area of c-Si PV, the output capacity of PV modules is also rising, as a reflection of the improvement of the solar cells conversion efficiency. Higher wattage PV modules have been released using high-efficiency solar cells, as well as half-cut or 1/3 cut or multicut solar cells. As the electrical resistance within these solar cells is reduced, the output drop due to the resistance heat generation will be curbed and the reduction of conversion efficiency under high temperatures in the summer can be suppressed as well, which is said to lead to increase in total power generation volume. In 2019, about two-thirds of newly installed PV module manufacturing lines adopted the half-cut solar cell technology. As mentioned before, the commercialization of PV modules with larger wafers has started. Other technologies such as the shingled PV module technology (overlapping the edges of solar cells without ribbons) and the seamless soldering technology are also adopted. With these technologies, the output capacity of PV modules is increasing and > 500W or > 600 W c-Si PV modules are being commercialized or underway for commercialization. It is also reported that bifacial PV modules using either PERC or heterojunction solar cells on both sides of the module are rising, to generate more power and a lower LCOE, seeking higher IRR. Bifacial PV modules are expected to achieve the lowest LCOE with single axis trackers in utility-scale applications. They are used for agroPV and floating PV applications as well. It is expected that the share of bifacial PV modules will reach 50% by the end of 2023.

With the price reduction of c-Si PV modules, modules for building integrated PV (BIPV) systems have been commercialized, such as modules with coatings on the surface glass and colored films.

Approx. 4,1 GW of thin-film PV modules were produced in 2019. Thin-film PV modules were mainly produced in Malaysia, USA, Japan, Germany, and China, as in the previous year. First Solar of USA remained the world's largest thin-film PV module manufacturer. First Solar owns factories in the USA, Malaysia, and Vietnam, and it produced 5,2 GW of CdTe thin-film PV modules in 2019. As for thin-film PV other than CdTe thin-film PV, a total of 0,6 GW of CIGS PV modules were produced in 2019 in Japan, Germany, USA, etc. As for thin-film PV, new production bases are being established in China, and production of CIGS and CdTe thin-film PV modules has been reported. China National Building Materials (CNBM) started the operation of a CIGS thin-film PV module factory in the Sichuan province in China. The company is also manufacturing CdTe thin-film PV modules. In China, there are also some other companies manufacturing thin-film PV modules. In many of the IEA PVPS member countries, R&D and commercialization efforts for the improvement of conversion efficiency and throughput, as well as for the enlargement of the module size have been continuously reported for CIGS thin-film PV modules. As for thin-film PV modules, proposals have been made on those with flexible substrates which can be installed on curved surfaces, light transmitting PV modules, roof tile-integrated PV modules for BIPV systems, and so on.

The average spot price of PV modules in the beginning of 2019 was 22 USD cents/W. It gradually decreased to 19 USD cents/W by the end of the year. This decline is the result of the widening gap between supply and demand. The price reduction of polysilicon and the reduction of polysilicon usage also contributed. This situation has continued giving a negative impact on the profit structure of major PV module manufacturers. Under such circumstances, the integration of manufacturers has been accelerated.

FIGURE 4.7: YEARLY PV INSTALLATION, PV PRODUCTION AND PRODUCTION CAPACITY 2008 - 2019



SOURCE IEA PVPS, RTS CORPORATION.

Figure 4.7 shows the trends of global yearly PV installation, PV module production and production capacity. The PV installed capacity in 2019 grew to 115 GW. It is estimated that , by the end of the year, the PV module production volume and its manufacturing capacity were 140 GW and 220 GW/year, respectively. The operation ratio of PV module production in 2019 was 64%, almost at the same level as the previous year (63%). It should be noted that the production capacity figures include the capacities of aged facilities and idle facilities that are not competitive, the effective production capacity is assumed to be at the level of approx. 180 GW/year in 2019. By summing up announced new capacity of PV modules, the production capacity may reach more than 250 GW/year.

It is observed that the gap between supply and demand was not balanced due to the continued enhancement of the production capacity including the improvement of conversion efficiency and the output of PV modules by major manufacturers.

Furthermore, high-efficiency multi-junction PV cells/modules have been produced, using mainly III-V materials. They are mostly used for satellite or unmanned aerial vehicles and concentrating PV (CPV) systems. Installation of high-efficiency multi-junction PV devices on vehicles has been studied at the stages of R&D and demonstration. Germany, USA, France, Japan, and Spain are continuously conducting R&D activities on high-efficiency multi-junction PV cells/modules. R&D for tandem solar cells using crystalline silicon and multi-junction cells is also active in these countries. Hydrogen synthesis using high-efficiency cells is also studied. Application of CPV for AgroPV is researched as well because of its space efficiency.

Following the rapid improvement of the conversion efficiency in a short time, efforts on mass production of perovskite PV cells/modules were reported in 2019. For instance, GCL Nano Science (China) under GCL Group (China), started working on the development of a 100 MW/year mass production line in the beginning of 2019, aiming to start mass production of perovskite PV modules in 2020. In July 2020, Hangzhou Microquanta Semiconductor, China started construction of perovskite PV factory aiming to have 5 GW/year. Saule Technologies (Poland) aims to start mass production of flexible perovskite solar cells by 2021. In the USA, Swift Solar is working on commercialization of flexible PV modules. Also, efforts on mass production of perovskite/c-Si solar cells were reported. Oxford PV (UK) made announcements on financing, as well as a partnership with an equipment manufacturer, aiming to start mass production at the 200 MW/year manufacturing line by 2020.

THE UPSTREAM PV SECTOR / CONTINUED

TABLE 4.2: EVOLUTION OF ACTUAL MODULE PRODUCTION AND PRODUCTION CAPACITIES

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

NOTE: ALTHOUGH CHINA JOINED IEA PVPS IN 2010, DATA ON CHINA'S PRODUCTION VOLUME AND PRODUCTION CAPACITIES FROM 2006 ONWARDS ARE INCLUDED IN THE STATISTICS.

SOURCE IEA PVPS & OTHERS.

THE DOWNSTREAM SECTOR

An overview of the downstream sector from the PV industry can be described as in Figure 4.8 (example of utility-scale projects).

PV developers have been active in PV power plant developments in the countries where power purchase agreements (PPAs) are guaranteed under auctions, and where feed-in tariff (FIT) programs and other mechanisms are implemented. While developers sell PV power plants to Independent Power Producers (IPPs) or investors called asset owners, some developers own PV power plants as their own assets.

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 EPC together with operation and maintenance (O&M) services by themselves. Some companies develop PV power plants and own them, while others provide EPC and own the plants until they sell them 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.

In some cases, PV electricity is sold directly to private companies, who procure electricity generated by renewable energy sources. This occurs in places where the electricity market is liberalized and at the same time where it is systematically possible. These contracts are called Corporate PPA (CPPA). According to the "Global Trends in Renewable Energy Investment 2020" report, published by UNEP (the United Nations Environment Programme), 19,5 GW of electricity from renewable energy sources was contracted via CPPA in 2019. This represents a 43% increase from 2018. However, regional differences are significant due to regulatory issues. Major CPPA markets are in the USA and Europe. In the countries where the national electric utility companies dominate the market, CPPA is either not allowed or only allowed for specific cases.

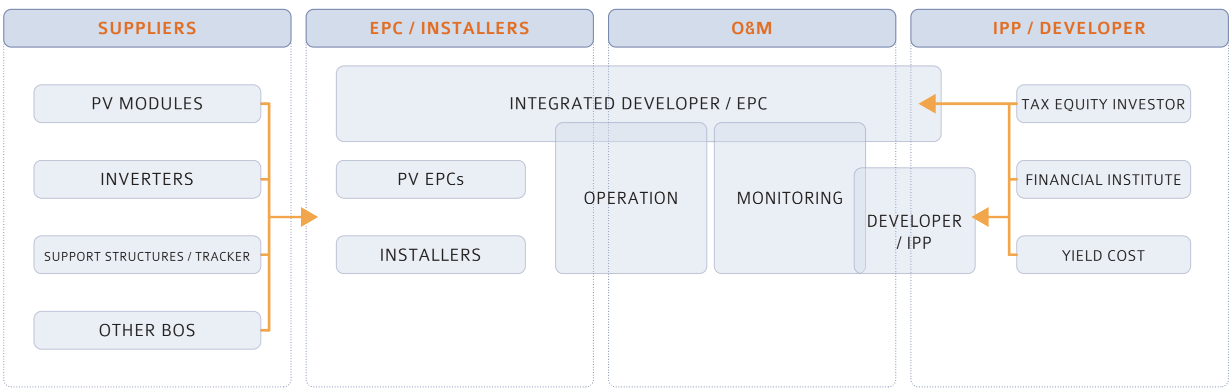
Following the reduction of the PV generation cost, some cases were reported, where IPPs trade PV electricity on the electricity trading market without subsidies. This business model, called "Merchant PV", is active in European countries such as Spain, Italy, UK, etc.

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 enhancing overseas business deployment and are active in business deployment in emerging markets such as Africa, the Middle East and Latin America. The number of project developers deploying international business is increasing. As in 2018, utility-origin or conventional energy-origin companies, namely Engie (France), EDF (France), Total (France), Enel (Italy), RWE (Germany), E.ON (Germany), Acciona (Spain), Shell (UK/Netherland), and BP (UK) have been expanding their business in the PV and other renewable sectors.

Global major oil companies are also shifting to the renewable energy business. These companies are either committed to achieving net zero energy or making investments for the energy transition. Thus, they are actively enhancing related business through acquisitions or by forming partnerships on a global scale.

Asian electric utilities are also active in the renewable energy business. The Malaysian national electric power company, Tenaga Nasional developed utility-scale PV projects in Malaysia. Petronas, Malaysian state-owned oil company acquired Amplus Energy Solutions having 500 MW of PV project portfolio in 2019 and invested in SOLS Energy for distributed PV power in July

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



SOURCE IEA PVPS & OTHERS.

THE DOWNSTREAM SECTOR / CONTINUED

2020. It was reported that PetroChina decided to enter the PV and wind power generation business. KEPCO, a Korean national electric power company is actively working on renewable energy projects in Asia, Americas and Africa.

It should also 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 (Canada) and Hanwha Solutions (Korea) are also active in the downstream sector. Notable polysilicon manufacturers investing in the international downstream business are GCL-Poly Energy (China) and OCI (Korea). Thin-film PV module manufacturer First Solar announced withdrawal from the EPC business in the USA in September 2019.

In 2019 and later, a number of PV plus storage batteries projects are announced under auction and other frameworks in Australia, USA, Portugal, South Africa, India, etc. In South Korea, under the RPS scheme, an increasing number of PV plus storage projects are being developed, supported by the policy measure to issue Renewable Energy Certificates (REC) with a multiplier. From Japan, it was reported that storage batteries were installed at a utility-scale PV power plant in Hokkaido Prefecture, in response to the request from local electric utility company. In addition to storage projects, hybrid projects installing PV and wind power generation and PV plus pumped hydro were also reported as one of the measures to support variable renewable energy sources.

The picture of the downstream sector for distributed generation is different from that of utility-scale PV applications. Distributed PV systems for residential, commercial and industrial applications are owned generally by the building owners or third-party companies. In some countries, the third-party ownership (TPO) business model is quite active. The companies using the TPO business model provide PV systems to property owners and sign an agreement to supply PV electricity usually at a lower price than the retail electricity price. These companies also provide loans to customers who want to keep the ownership of PV systems.

The demand for storage batteries for distributed PV systems has been rising in the markets where PV systems have already been widely installed such as the states of California and Hawaii in the USA, Australia and Germany. In Germany, it is reported that around 90% of new residential PV systems including storage batteries were installed in 2019. In Australia, 22 661 decentralized storage systems were installed in 2019.

Services to install off-grid PV systems in non-electrified areas in Africa and other nations are also active. The small-scale off-grid PV business is active through a divided payment of the handling charge and a usage fee called pay-as-you-go (PAYG) scheme. There is also a rental with purchase option. The PAYG scheme is implemented mainly in countries or regions having difficulty with the electricity access. According to the Global Off-Grid Lighting Association (GOGLA), 8,5 million solar lighting and 1,2 million off-grid PV systems were installed in 2019 and the PAYG model significantly contributed to the PV market for improving electricity access.

BALANCE OF SYSTEM COMPONENT MANUFACTURERS AND SUPPLIERS

Balance of system (BOS) component manufacturers and suppliers represent an important part of the PV value chain and BOS components are accounting for an increasing portion of the system cost as the PV module price is falling. Accordingly, the production of BOS products has turned into an important sector of the overall PV industry.

The inverter technology has become the focus of interest since the penetration ratio of grid-connected PV systems has increased to the extent that it represents now close to 99% of the market. Since the new grid codes require the active contribution of PV inverters to do grid management and grid protection, new inverters are now being developed with sophisticated control and interactive communications features. With these functions, the PV power plants can actively support the grid management, for instance, by providing reactive power and other ancillary services. In case of distributed PV systems, advanced inverters play a key role for the storage battery management, communication, monitoring, controlling home appliances, as well as charging EVs.

PV inverters are produced in many IEA PVPS member countries such as China, Japan, South Korea, Australia, USA, Canada, Germany, Spain, Austria, Switzerland, Italy and Thailand. Originally, the supply structures of PV inverters were affected by national codes and regulations so that domestic or regional manufacturers tended to dominate domestic or regional PV markets. However, lower price imported products started to increase their share in countries and market segments where the cost reduction pressure is strong. In such markets, leading players with global supply chains are taking the share of regional players.

It is estimated that Chinese inverter manufacturers supplied 73,5 GW of inverters in 2019, a 11,9% increase from the 65,7 GW provided in 2018. About 40,3 GW and 12 GW of OEM products were exported. Major export destinations are India, Europe, Latin America, USA and Japan. According to CPIA, Chinese inverters accounted for 77% of the European PV market in 2019, 61% in India, 58% in Latin America, the Middle East and Japan. It is estimated that the Chinese manufacturers' share in the global PV inverter market was around 60% in 2019, almost the same level as in 2018 (61%). While in 2011, China counted only with one inverter manufacturer (Sungrow) in the top 10 ranking, whereas in 2019, five Chinese companies were in the top 10 ranking for their shipment volume (Huawei, Sungrow, Sineng, Growatt and Ginlong Solis), the same number as 2018; even though the top ranked companies are not the same.

The typical products dedicated to the residential PV market have rated output powers ranging from 1 kW to 10 kW, for single phase (Europe) or split phase (USA and Japan) grid connection. For utility-scale applications, 3 to 4 MW centralized inverters are common. 5 MW inverters are also available. The share of string inverters is increasing for large-scale PV systems. The string inverter size is also increasing and exceeding 200 kW level. Larger sized inverters with higher DC voltage, up to 1500 V, reduce BOS cost with longer strings. In the utility-scale segment, one of the new business models for inverter companies is the repowering business. Manufacturers established a repowering sector aiming at replacing the demand for utility PV power plants operated for more than 10 years.

Inverter technologies have improved thanks to the adoption of new power semiconductor devices such as SiC and GaN. These devices achieved higher conversion efficiencies, together with a reduction in size and weight, resulting in lower LCOE. Meanwhile, inverters are now required to have smarter control functions as well, to realize autonomous adjustment functions for the grid stabilization (voltage stabilization, frequency stabilization, power factor adjustment, output curtailment, soft start, etc.). An increasing number of manufacturers propose inverter and PV storage solutions for the market where self-consumption is the major driver. In this sector of distributed generation, packaged products consisting of PV and storage batteries with Home Energy Management Systems (HEMS) or Building Energy Management Systems (BEMS) are proposed or sold by integrators.

The Module Level Power Electronics (MLPE) market, consisting of microinverters and DC optimizers (working at module level), is expanding, especially in the USA. MLPE can help achieving a higher output for PV arrays which are affected by shading and a more efficient rapid shutdown can be conducted in case of fire.

Just like PV module suppliers, inverter manufacturers have been suffering from the significant cost pressures and severe competition. Reorganization, mergers, and acquisitions of inverter manufacturers have been reported in 2019. In January 2019, KACO new energy (Germany) announced that it sold the central inverter business to OCI Power (Korea). The company also announced a plan to sell the string inverter business to Siemens (Germany) and to focus on the storage system business and the smart infrastructure business. In February 2019, Schneider Electric (France) disclosed its plan to withdraw from the central inverter business and concentrate on the string inverter business for residential and commercial applications. In July 2019, ABB (Switzerland) agreed to sell the PV inverter business to FIMER (Italy) and the deal was completed in March 2020. In the MLPE sector, SunPower Corporation (USA) sold the microinverter business to Enphase Energy (USA) in August 2018.

The production of specialized components such as tracking systems, PV connectors, DC switchgears and monitoring systems, represents an important business for many large-scale electric equipment manufacturers. With the increase of utility-scale PV power plants, the market for single-axis trackers has been growing. In 2019, it is estimated that around 40% of utility-scale PV projects installed in 2019 adopted single-axis trackers. According to Solar Energy Research Institute of Singapore (SERIS), the combination of single-axis trackers and bifacial PV modules can achieve the highest cost effectiveness across the most parts of the world. It is expected that the lowering PPA price will drive further growth of the single-axis tracker market.

TRADE CONFLICTS

Trade conflicts over PV products, including polysilicon, continued having an impact on the business strategy of PV companies. In this section, the trends of major trade conflicts observed in 2019 and later are described.

In 2018, the USA, which is one of the major PV markets, implemented safeguard measures under the Section 201 of the US Trade Act of 1974. A safeguard tariff towards c-Si PV modules was then introduced. The measures were implemented on February 7, 2018 and are effective for four years. The tariff imposed on c-Si PV cells and modules imported to the USA is 30% in the first year, 25% in the second year, 20% in the third year and 15% in the fourth year. However, the tariff on solar cells will be exempt for up to 2,5 GW/year of import. Beneficiary countries of Generalized System of Preferences (GSP), which aims to support developing countries, and countries accounting for less than 3% of total US import are exempt from the safeguard measures. At the beginning, it was calculated that the installation cost of a utility-scale PV system in the USA will increase by about 10 USD cents/W in case a 30% tariff is imposed, and negative impacts on the electricity business market were concerned. However, due to the price reduction of PV modules, the impacts of the safeguard tariff were limited. Meanwhile, major Chinese and Korean PV manufacturers set up PV module manufacturing bases in the USA and the manufacturing capacity of PV cells/ modules in the USA increased from 2 GW/year as of the end of 2017 to 6,6 GW/year as of the end of 2019.

As for the safeguard measures, changes regarding the items subject to the safeguard measures and an addition of the countries subject to these measures were announced. In June 2018, interdigitated back contact (IBC) and busbar-less c-Si PV cells and modules were exempted from the safeguard measures. In May 2019, Turkey, which was initially exempt from the safeguard measures, was added to the list of countries subject to the measures, as well as India in June 2019. In June 2019, it was announced to exclude bifacial PV cells and modules from the subjects of the safeguard measures. Then, the U.S. Trade Representative (USTR) announced re-imposition of duty on bifacial products in November 2019. However, the U.S. Court of International Trade (CIT) allowed exclusion of bifacial modules. In April 2020, USTR tried to remove exemption for bifacial PV modules again but CIT suspended.

Under the section 301 of the US Trade Act of 1974 towards China, the second sanction took effect in August 2018, which imposed 25% tariff on PV cells and modules. Then in September 2018, the third measures were implemented, which initially imposed 10% tariffs on inverters, AC modules with microinverters embedded in PV modules, and the tariff was increased to 25% in May 2019. However, the impacts are expected to be little since most Chinese PV module manufacturers have shifted their manufacturing bases for shipping to the USA to countries such as Vietnam, Malaysia,

TRADE CONFLICTS / CONTINUED

Thailand, etc. Inverter and MLPE manufacturers having manufacturing bases in China, announced to utilize their manufacturing bases in countries such as India and Mexico to avoid the imposition of the safeguard tariff. Huawei Technologies (China), which ranked first in the global inverter shipment in 2018, admitted its policy to withdraw from the US PV market due to the trade conflicts with the USA over communication equipment. In September 2019, Trump administration imposed a 15% duty on Chinese import. The percentage of this duty was lowered to 7,5% in February 2020 corresponding to the first step agreement between China and the US.

Moreover, antidumping duties (AD) and countervailing duties (CVD) measures on PV modules using Chinese solar cells (which took effect in 2012) as well as AD and CVD measures on Chinese and Taiwanese c-Si PV cells and modules (which took effect in 2015), are still active in the USA. Other duties on imported steel (25%) and Aluminum (10%) effective since March 2018 give impacts on the cost of support structures and frames of PV modules.

China terminated imposition of AD and CVD on European polysilicon in October 2018. Meanwhile, AD and CVD on polysilicon manufactured in the USA and Korea, which have been imposed since 2014, still continue. The tariff rate for Korean products was revised in November 2017. This measure was scheduled to terminate in January 2019. However, the tariff is still imposed since the Chinese Ministry of Commerce decided to implement a sunset review (an investigation to judge whether to terminate AD measures). In 2019, China conducted a sunset review of duties on polysilicon and decided 5 years extension in January 2020. In July 2019, REC Silicon (Norway) which has its manufacturing base in the USA, decided on a long-term closure of its polysilicon factory in Moses Lake, Washington. REC Silicon established a joint venture with a Chinese company for a fluidized base reactor (FBR) process-based polysilicon factory in China, which is currently in operation.

In India, the government imposed several duties on PV modules and other related materials. In July 2018, a safeguard duty was imposed on imported PV cells/modules from China, Malaysia and other advanced countries. Duties were 25% during the first year, then 20% the first 6 months of the second year and dropping to 15% later. After reviewing the safeguard duty, one-year extension for products imported from China, Thailand and Vietnam was decided in July 2020 while Malaysian products were exempted. In addition to the safeguard duties, the Indian government is considering the imposition of a 15 to 20% Basic Custom Duty (BCD) on imported PV products including solar cells, PV modules and inverters. At the time of writing this, imposition of BCD is not yet announced. The Indian government aims to establish local manufacturing capacity and duties are imposed on glass for PV modules from China (effective from August 2017) and Malaysia (effective from February 2019).

In Turkey, the Ministry of Economy decided to impose duty on Chinese PV modules from April 2017. Original duty was 300 USD/m^2 (approximately 30 to 35% increase of the price). In April 2020, the basis of the duty changed to 25 USD/kg.

The PV sector has significant ramifications 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.

VALUE FOR THE ECONOMY

The turnover of the PV sector in 2019 amounted to around **135 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 **5,4 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.

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 4%. On the other hand, the global value for O&M has slightly decreased in our estimates (about 20%) due to more realistic costs figures. It should however be considered that this part of the PV economy is going to grow, 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.

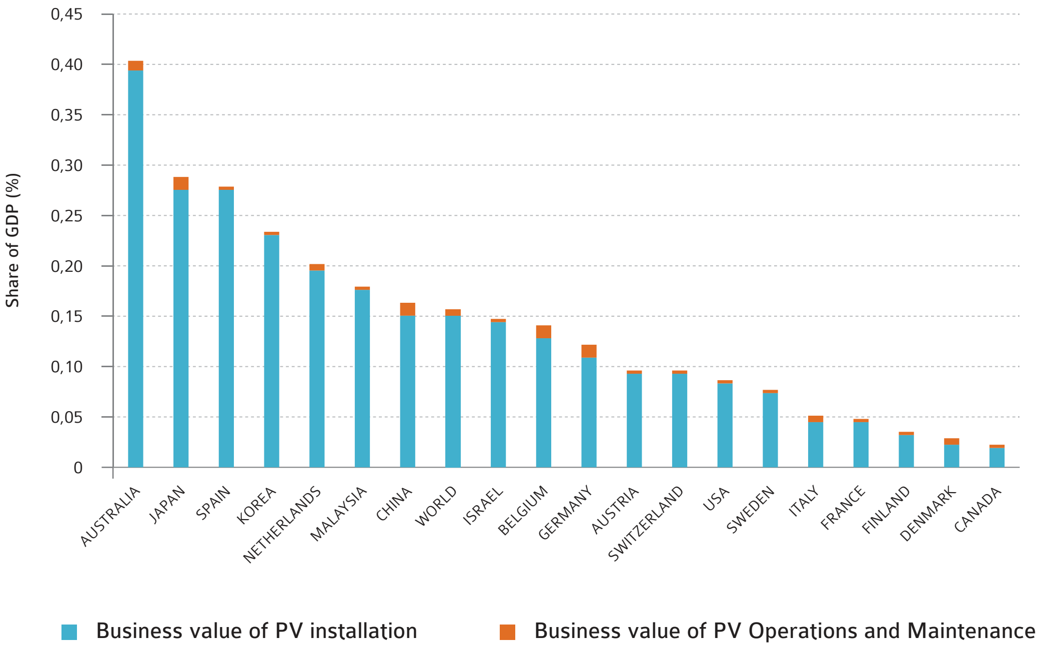
CONTRIBUTION TO THE GDP

Figure 5.1 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 5.1, the business value of PV compared to GDP represented less than 0,4% in all considered countries and more than 0,05% in most of them, a range very similar to last year. Two countries show major notable evolutions of their values compared to last year, Spain and China, in link with the important evolutions of their respective markets. Spain saw an increase of the business value of PV from around 0,02% of its GDP in 2018 to 0,28% in 2019 due to the impressive surge of its market. On the contrary, the share of PV in China's GDP dropped from slightly below 0,30% in 2018 to 0,16%, because of the significant market contraction in the country.

VALUE FOR THE ECONOMY / CONTINUED

FIGURE 5.1: BUSINESS VALUE OF THE PV MARKET IN 2019



SOURCE IEA PVPS & OTHERS.

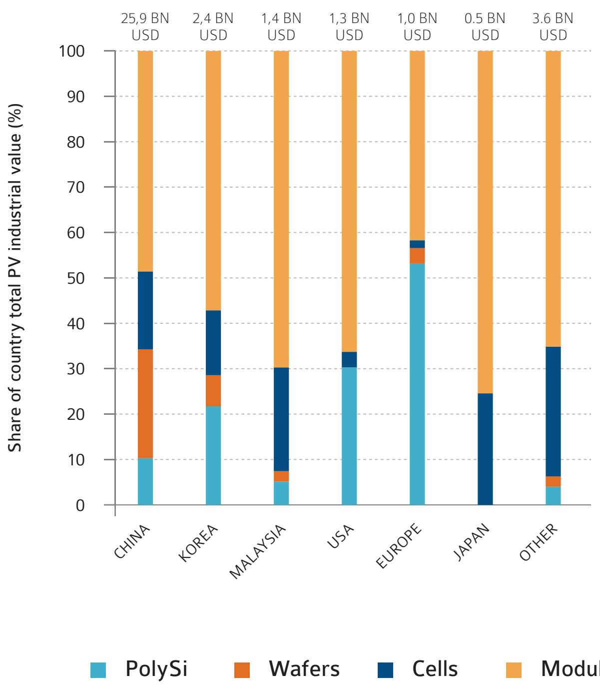
INDUSTRIAL VALUE OF PV

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 taken into account are based on average prices reported by member countries. We consider that equipment and materials are included in this computed value. BoS is not considered here.

The estimated global industrial value of PV established itself around 36 Billion USD in 2019. Figure 5.2 shows the details of estimated values for IEA PVPS major PV manufacturing countries compared to their GDP. In addition, it shows the share represented by each step of the value chain in the PV industrial value for each country in relative terms.

FIGURE 5.2: INDUSTRIAL BUSINESS VALUE OF PV IN 2019



SOURCE IEA PVPS & OTHERS.

China, by far the predominant manufacturing country in all steps of the PV value chain, shows an approximate share of 0,18% 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, nearing 0,40%. Korea shows an approximate 0,15% share, while remaining countries do not exceed 0,01%.

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. The value of the BoS globally reached 34 Billion USD in 2019.

EMPLOYMENT IN PV

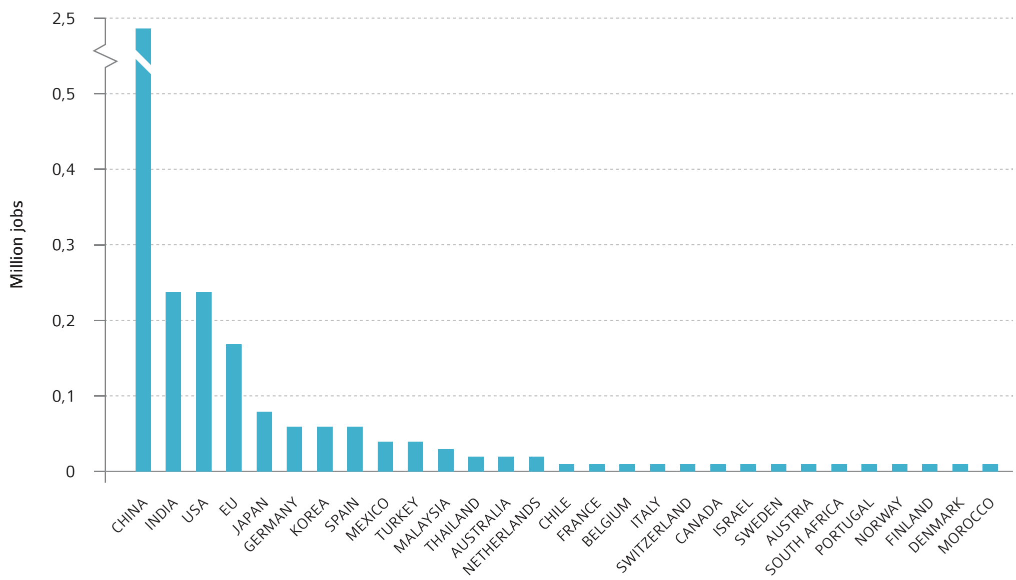
Figure 5.3 gives an overview of the total jobs in IEA PVPS countries and India. Reported numbers have been established based on the IEA PVPS National Survey Reports and additional sources such as the IRENA jobs database. It should be noted that these numbers are strongly dependent on the assumptions 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 up to 3,5 million people globally at the end of 2019. An estimated 1,3 million were employed in the upstream part, including materials and equipment, while 2,2 million were active in the downstream part, including O&M.

As the leading producer of PV products and the world's largest installation market, China is markedly leading PV employment with around 2,2 million jobs in 2019, which corresponds to a significantly higher job intensity than almost anywhere else. Lower by one order of magnitude, India and the USA come second and third in the ranking with about 240 000 jobs each. The European Union shows a total PV employment of about 170 000 FTE, followed by Japan that takes the fourth place with around 74 600 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. In other words, 2,2 million people worked one way or another for the downstream part of the PV sector globally in 2019.

FIGURE 5.3: GLOBAL EMPLOYMENT IN PV PER COUNTRY



SOURCE IEA PVPS NSRS AND IRENA RESOURCE DATABASE.

EMPLOYMENT IN PV / CONTINUED

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 20. 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. 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 10 FTE per MW produced while the downstream part generates around 20 FTE per MW installed.

With an estimated total of 3,5 million jobs in the solar PV sector worldwide in 2019, 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.

The emergence of PV as a mainstream technology wakes up the 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.

PV FOR SOCIAL POLICIES

Besides its direct value in 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, 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 aims 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 leads to an additional annual income of over 3 000 CNY for these households through the selling of the generated PV electricity. In 2019, the established policy of 2018 was maintained.

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 microhydro-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.

In Italy, the Municipality of Porto Torres (Sardinia Region), with the collaboration of Gestore dei Servizi Energetici, introduced in 2017 the so called "reddito energetico" (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 (Scambio, Sul Posto, SSP) 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 for solar for low-income households were announced by State Governments in 2019, going from interest free loans to rebates or even complete subsidies.

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 have not been widely used yet. While the reputation of PV, especially in the European countries that started to fund its development, is the one of a costly energy source, increasing electricity prices, the reality of PV in 2020 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.

CLIMATE CHANGE MITIGATION

Climate change has become one of the key challenges that our societies have to overcome and PV is definitely 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 33,3 Gt CO_2eq in 2019.[3] From this amount, around 13 Gt are attributed to the power sector.

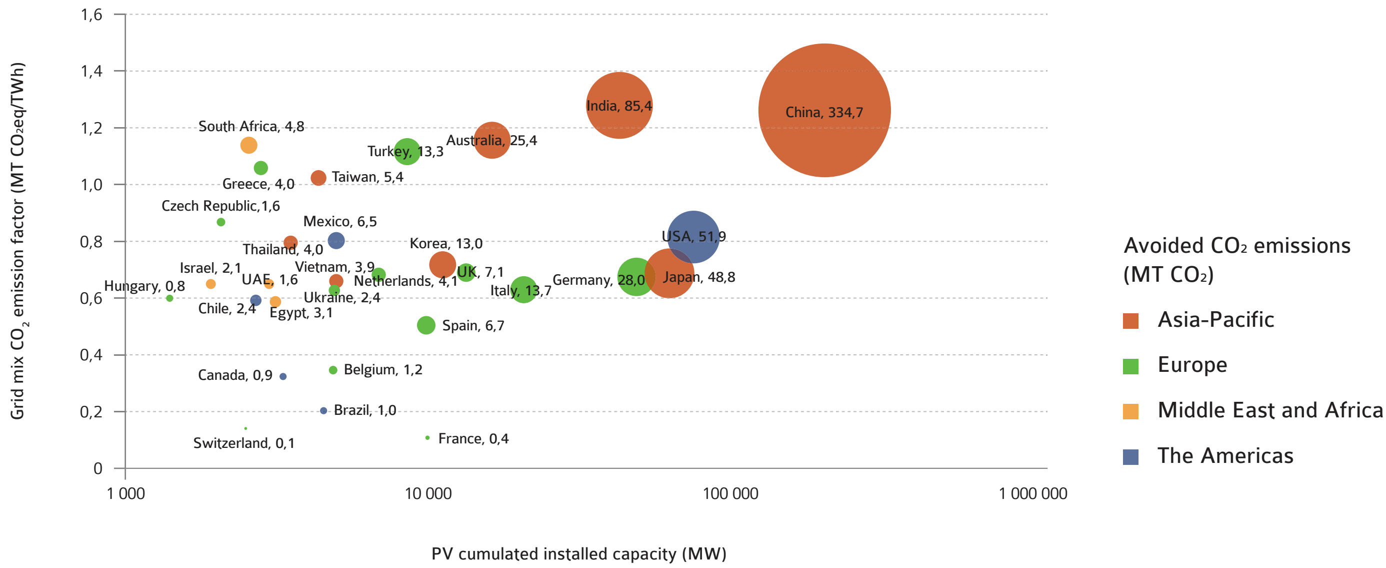
Increasing the PV share in the grid mix can significantly reduce the emissions from power generation. The global average carbon intensity of electricity is 463 gCO_2kWh[4] whereas for 1 kWh produced by PV the emitted CO_2, considered on a life cycle basis, can be as low as 15g depending on technology 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 2019 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 ($gCCO_2$/kWh) of both PV electricity and grid mix electricity are taken from the IEA PVPS Task 12 databases.

Using this methodology, calculations show that the PV installed capacity today avoids more than 700 Million Tonnes of CO_2 eq annually. While today PV represents around 3,3% of the global electricity demand, it avoids around 5,4% of the power 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 in China and India.

Figure 5.4 gives a view of the avoided CO_2 emissions in the first 30 countries in ranking of cumulated installed PV capacity and which represent in total around 97% 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 5.4: YEARLY CO_2 EMISSIONS AVOIDED BY PV



SOURCE IEA PVPS & OTHERS.

3 IEA – *Global CO_2 emissions 2019 – Article – 11 February 2020.*

4 IEA – *Tracking Power 2020.*

six

COMPETITIVENESS OF PV ELECTRICITY IN 2019

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.

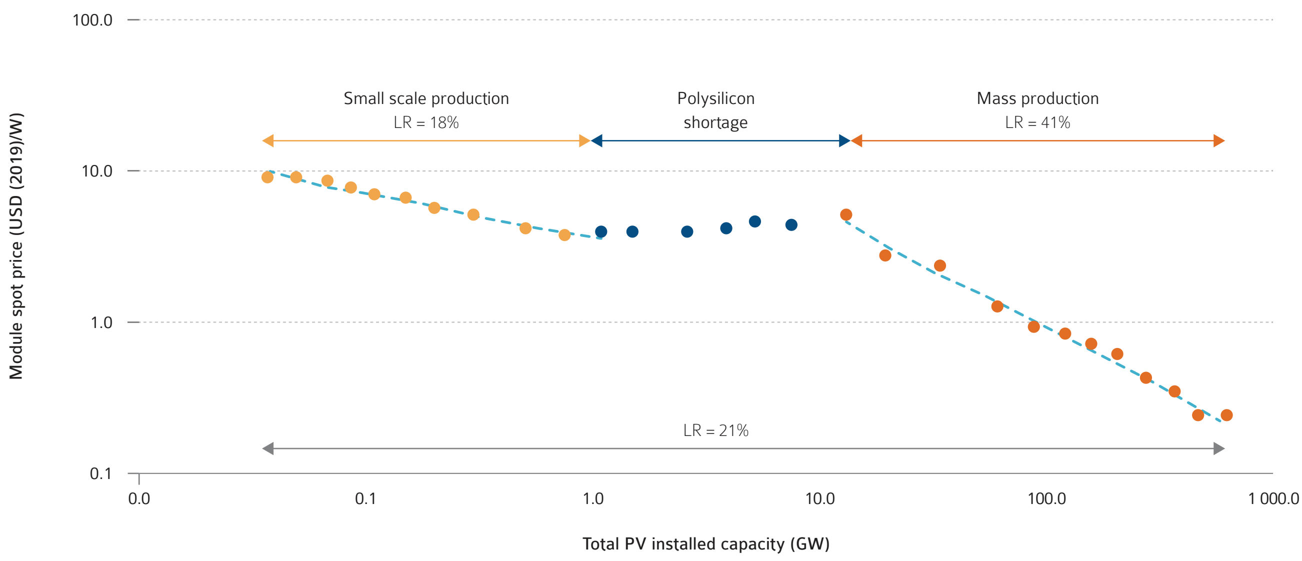
This section aims at defining where PV stands regarding its own competitiveness, starting with a survey of module and system prices in several IEA PVPS reporting countries. Given the number of parameters involved in competitiveness simulations, this chapter will mostly highlight the comparative situation 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.

FIGURE 6.1: PV MODULES SPOT PRICES LEARNING CURVE (1992-2020)

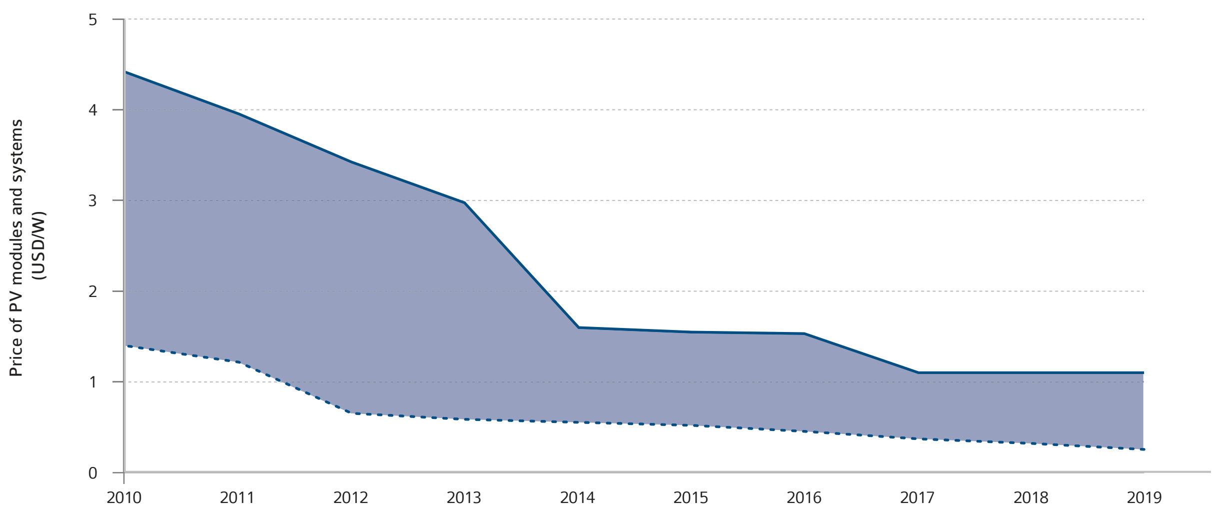


SOURCE IEA PVPS & BECQUEREL INSTITUTE.

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 continued to decline in 2019. More specifically lowest prices continue to fall while, a stabilisation or even an increase can be observed in countries with higher prices.

FIGURE 6.2: EVOLUTION OF PV MODULES PRICES RANGE



SOURCE IEA PVPS & OTHERS.

MODULE PRICES / CONTINUED

On average, the price of PV modules in 2019 (shown in Table 6.1) accounted for approximately between 40% and 50% of the lowest achievable prices that have been reported for grid-connected systems. In 2019, the lowest price of modules in the reporting countries was about 0,20 USD/W. It is assumed that such prices are valid for high volumes and late delivery (not for installations in 2019). However, module prices for utility-scale plants have been reported below the average values, down to less than 0,20 USD/W at the end of 2019.

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 2019. In 2020, the pandemic started to impact slowly the prices, with demand and supply being initially affected.

Prices below 0,20 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 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 are in general still in the 0,3 USD/W range for most producers.

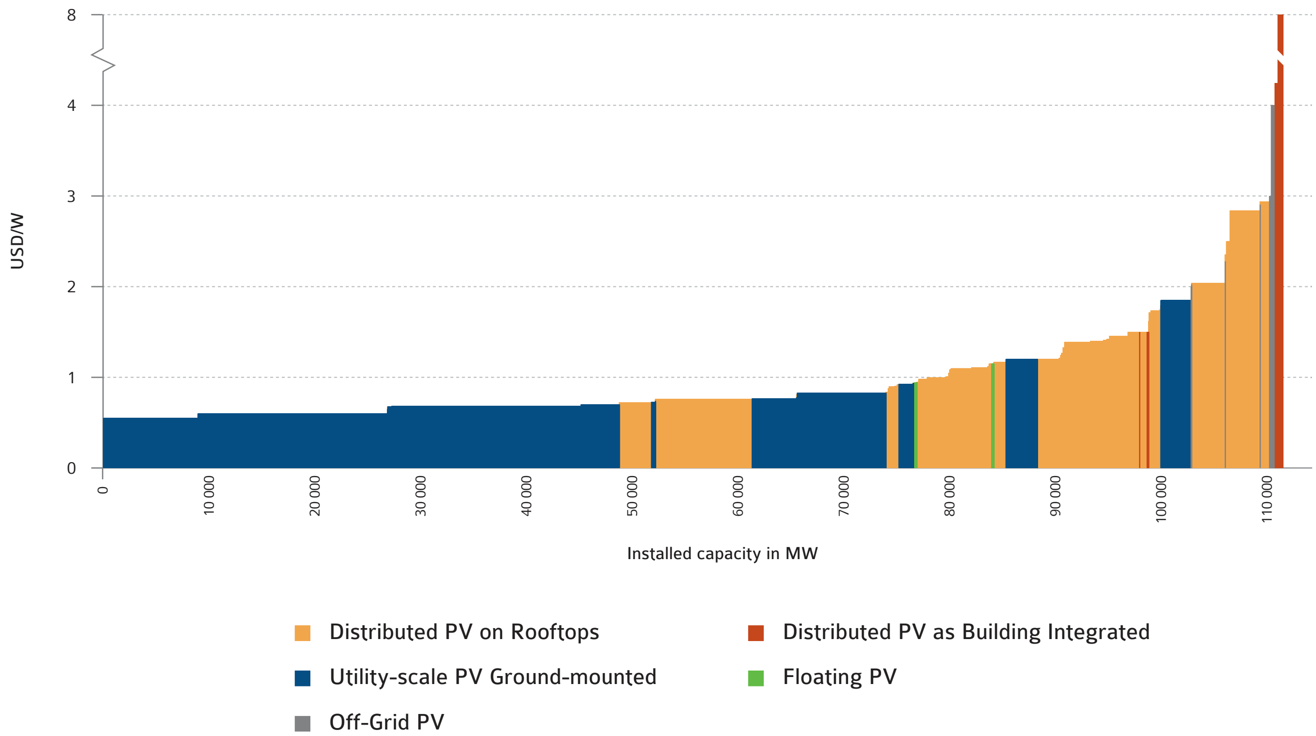
TABLE 6.1: INDICATIVE MODULE PRICES (NATIONAL CURRENCY AND USD/W) IN SELECTED REPORTING COUNTRIES

	CURRENCY	LOCAL CURRENCY/W	USD/W
AUSTRALIA	AUD	0,35 - 1,15	0,24 - 0,8
AUSTRIA	EUR	0,42 - 0,45	0,47 - 0,5
BELGIUM	EUR	0,22 - 0,62	0,25 - 0,69
CANADA	CAD	0,63	0,47
CHINA	CNY	1,68	0,24
DENMARK	DKK	4 - 6	0,3 - 0,5
FINLAND	EUR	0,2 - 0,3	0,22 - 0,34
FRANCE	EUR	0,4 - 0,45	0,45 - 0,5
ISRAEL	ILS	0,9537	0,27
ITALY	EUR	0,18 - 0,45	**0,2 - 0,5**
JAPAN	JPY	171	**1,57**
KOREA	KRW	280 - 600	0,24 - 0,51
MALAYSIA	MYR	0,88 - 1,05	0,21 - 0,25
SPAIN	EUR	0,31 - 0,53	0,35 - 0,59
SWEDEN	SEK	2,2 - 5,4	0,23 - 0,57
SWITZERLAND	CHF	0,35 - 0,73	0,35 - 0,73
USA	USD	0,4	0,4

NOTE: DATA REPORTED IN THIS TABLE DO NOT INCLUDE VAT.
GREEN = LOWEST PRICE. RED = HIGHEST PRICE.

SOURCE IEA PVPS.

FIGURE 6.3: 2019 PV MARKET COSTS RANGES



SOURCE IEA PVPS & BECQUEREL INSTITUTE.

SYSTEM PRICES

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

Figure 6.3 shows the range of system prices in the global PV market in 2019. It shows that almost 70% of the PV market consists in prices below 1 USD/W. Large distributed PV systems start around 0,7 USD/W while utility-scale PV saw prices as low as 0,50 USD/W. Lower figures have been seen in 2020 already. Floating PV and BIPV are given as indications given the low market development of these solutions. 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 in different prices. In general, the price range decreased from the previous year for all applications.

SYSTEM PRICES / CONTINUED

TABLE 6.2: INDICATIVE INSTALLED SYSTEM PRICES IN SELECTED IEA PVPS REPORTING COUNTRIES IN 2019

	GRID-CONNECTED (LOCAL CURRENCY OR USD PER W)								OFF-GRID (LOCAL CURRENCY OR USD PER W)	
	RESIDENTIAL		COMMERCIAL		INDUSTRIAL		GROUND-MOUNTED		>1 kW	
COUNTRY	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W	LOCAL CURRENCY/W	USD/W
AUSTRALIA	1,60	1,11	1,68	1,17	1,51	1,05	NA	N/A	N/A	N/A
AUSTRIA	1,56	1,75	0,8 - 1,19	0,9 - 1,33	0,75	0,84	0,70	0,78	2,04	2,28
BELGIUM	1,26	1,41	0,865 - 1,015	0,97 - 1,14	0,79	0,88	0,65	0,73	N/A	N/A
CANADA	2,5 - 2,75	1,88 - 2,07	2 - 2,5	1,51 - 1,88	1,8 - 2	1,36 - 1,51	1,25	0,94	N/A	N/A
CHINA	5 - 5,5	0,72 - 0,8	5 - 5,5	0,72 - 0,8	5 - 5,5	0,72 - 0,8	4,5 - 5	0,65 - 0,72	N/A	N/A
DENMARK	9 - 11	1,35 - 1,65	4 - 10	0,6 - 1,5	5 - 8	0,75 - 1,2	3 - 5	0,45 - 0,75	7 - 20	1,05 - 3
FINLAND	0,8 - 1,84	0,9 - 2,06	0,7 - 1,05	0,78 - 1,18	0,6 - 0,7	0,67 - 0,78	0,5 - 0,6	0,56 - 0,67	3 - 5	3,36 - 5,6
FRANCE	1,7 - 2,1	1,9 - 2,35	1 - 1,7	1,12 - 1,9	0,9 - 1,1	1,01 - 1,23	0,65 - 1	0,73 - 1,12	N/A	N/A
GERMANY	0,7 - 2,1	0,78 - 2,35	1 - 1,7	1,12 - 1,9	0,9 - 1,1	1,01 - 1,23	0,65 - 1	0,73 - 1,12	N/A	N/A
ISRAEL	5 - 6	1,4 - 1,68	3,5 - 4,5	0,98 - 1,26	3,50	0,98	NA	N/A	N/A	N/A
ITALY	1,2 - 1,6	1,34 - 1,79	0,95 - 1,25	1,06 - 1,4	0,8 - 1	0,9 - 1,12	0,5 - 0,8	0,56 - 0,9	N/A	N/A
JAPAN	321	2,94	222	2,04	222	2,04	202	1,85	N/A	N/A
KOREA	1 412 - 1 852	1,21 - 1,59	1 244 - 1 707	1,07 - 1,46	1 204 - 1 619	1,03 - 1,39	1 100 - 1 700	0,94 - 1,46	N/A	N/A
MALAYSIA	5,58	1,33	3,83 - 4,43	0,91 - 1,06	3,38	0,81	2,86	0,68	N/A	N/A
SPAIN	1,5 - 1,75	1,68 - 1,96	0,75 - 0,95	0,84 - 1,06	0,75 - 1	0,84 - 1,12	0,62 - 0,75	0,69 - 0,84	N/A	N/A
SWEDEN	11 - 17	1,16 - 1,8	7 - 16	0,74 - 1,69	7 - 13	0,74 - 1,37	5 - 9	0,53 - 0,95	25 - 30	2,64 - 3,17
SWITZERLAND	2,5 - 3,5	2,52 - 3,52	1,18 - 2,5	1,19 - 2,52	0,9 - 1,18	0,91 - 1,19	0,65	0,65	6,80	6,84
UNITED STATES	2,84	2,84	1,39	1,39	NA	N/A	0,83	0,83	N/A	N/A

NOTE: DATA REPORTED IN THIS TABLE DO NOT INCLUDE VAT.
GREEN = LOWEST PRICE. RED = HIGHEST PRICE.

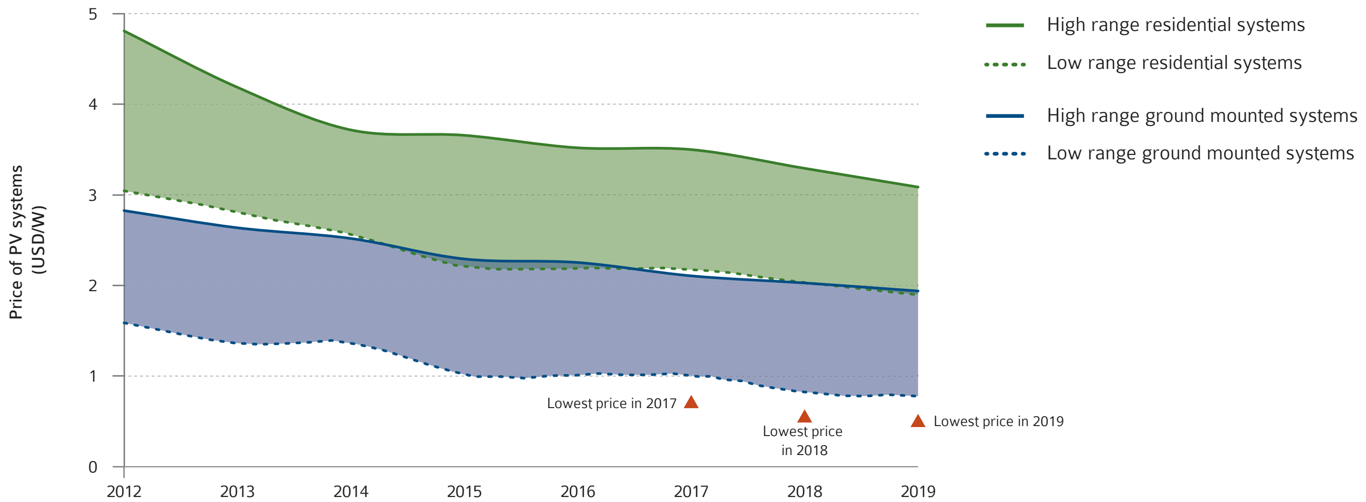
SOURCE IEA PVPS.

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 transport of components, technicians, without even mentioning the higher costs of maintenance. In 2019, the lowest system prices in the off-grid sector, irrespective of the type of application, typically ranged from about 1 USD/W to 5,6 USD/W but prices for some specific applications can be higher. The large range of reported prices in Table 6.2 is a function of 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 2019, a certain number of floating PV projects have been realized, in particular in Southeast Asia and in 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, one-off 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: EVOLUTION OF RESIDENTIAL AND GROUND MOUNTED SYSTEMS PRICE RANGE 2012 - 2019



SOURCE IEA PVPS & OTHERS.

The lowest achievable installed price of grid-connected systems in 2019 also varied between countries as shown in Table 6.2. 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 continued to go down in 2019, through a decrease in module prices, balance of system, soft costs and margins. System prices significantly below 0,6 USD/W for large-scale PV systems are now common in very competitive tenders. The range of prices tends to converge, with the lowest prices decreasing at a reduced rate while the highest prices are reducing faster. 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.

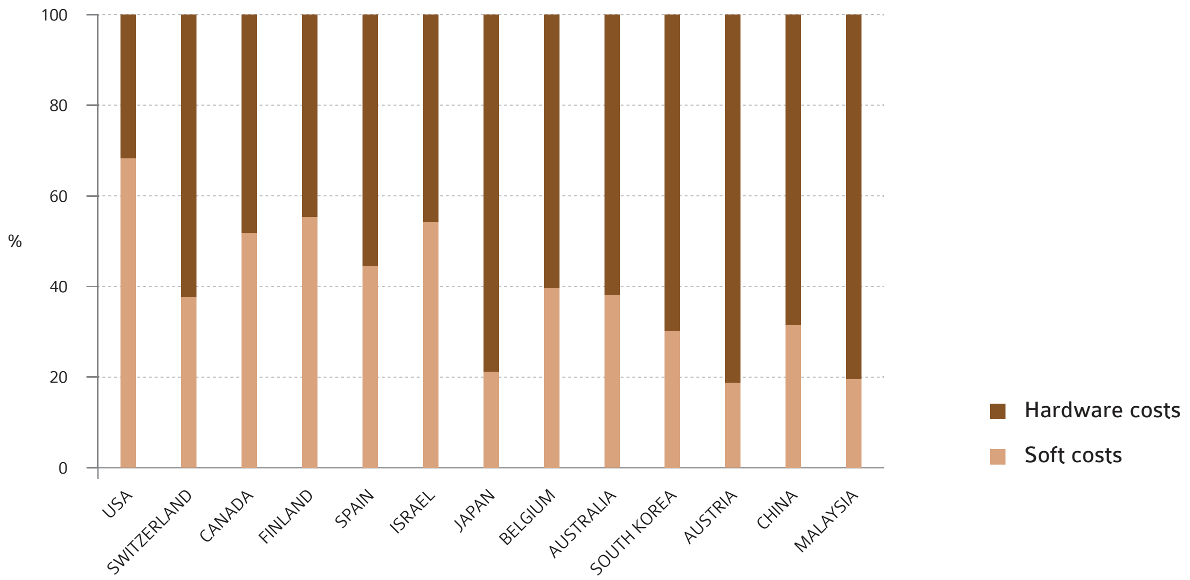
SYSTEM PRICES / CONTINUED

RESIDENTIAL PV SYSTEMS

System prices for residential PV systems reveal huge discrepancies from one country to another: the final price of modules, but also the other price components, such as the inverter, the rest of the BoS and the installation costs. The following figures illustrate such differences which in general might be explained by the local regulations, the size of the market and the market segmentation which can be diverse.

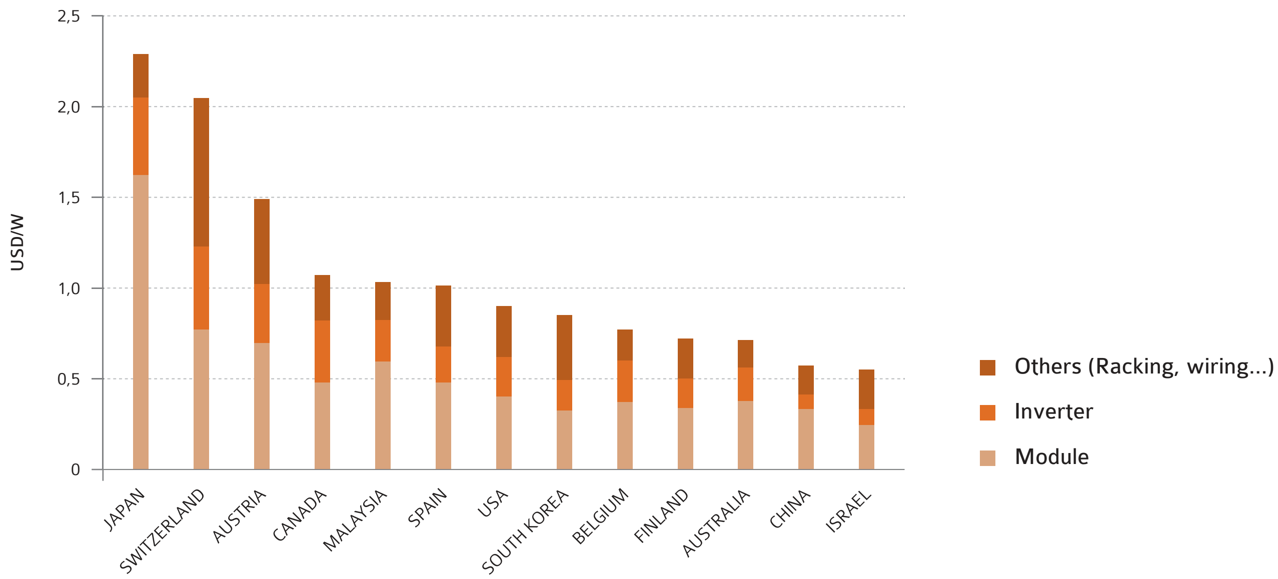
When analysing Figures 6.5 and 6.6, not surprisingly hardware costs represent a more important share in the total costs in the countries with higher hardware costs such as Austria, Japan and Korea.

FIGURE 6.5: AVERAGE COST BREAKDOWN FOR A RESIDENTIAL PV SYSTEM < 10kW



SOURCE IEA PVPS.

FIGURE 6.6: RESIDENTIAL SYSTEM HARDWARE COST BREAKDOWN

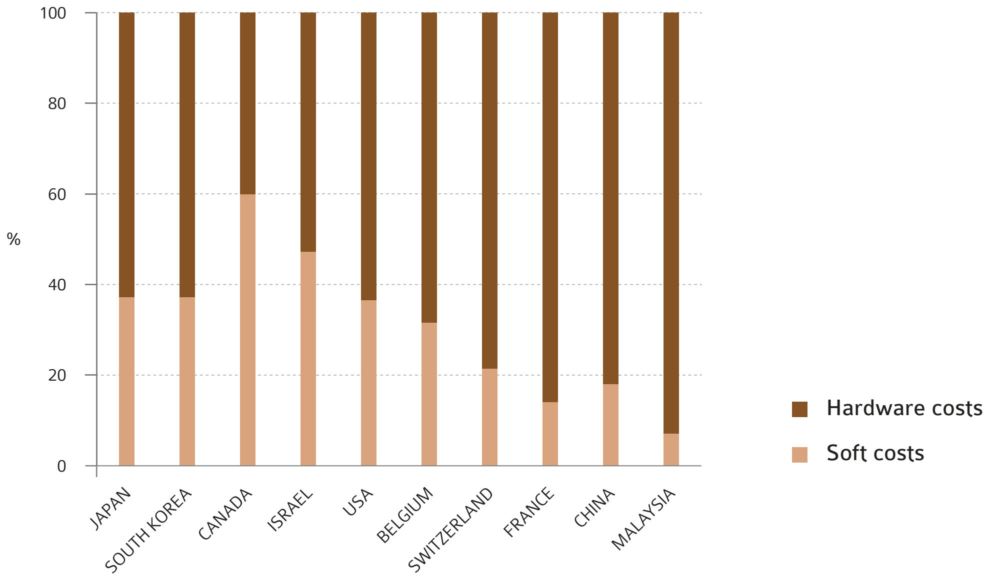


SOURCE IEA PVPS.

UTILITY-SCALE PV SYSTEMS

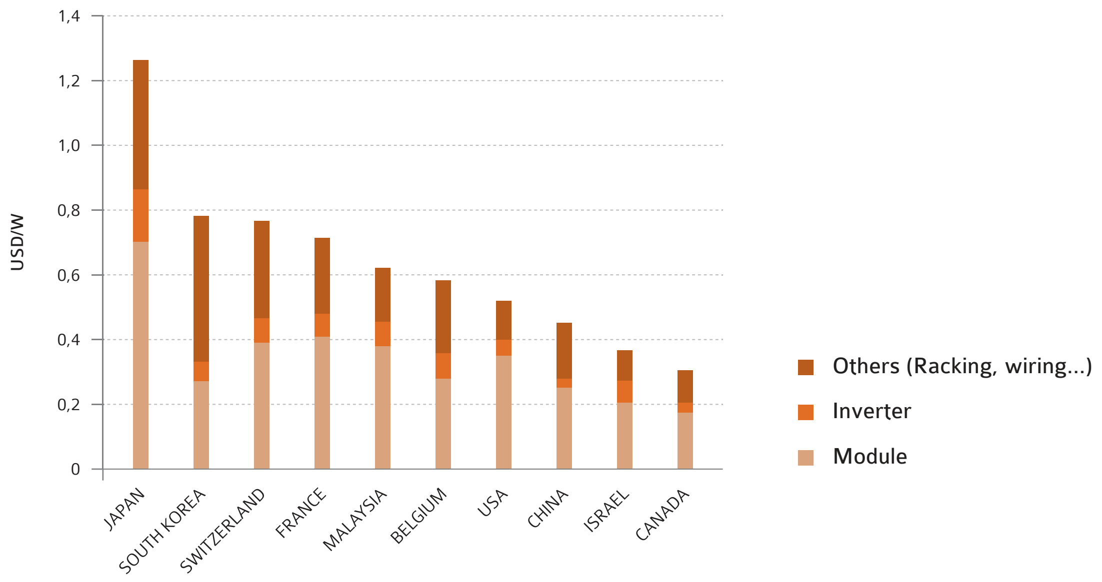
Disparities across countries can also be observed for utility-scale PV systems prices even though these are less important than for residential PV systems. Indeed, in most countries a large dominance of hardware costs over soft costs can be observed.

FIGURE 6.7: AVERAGE COST BREAKDOWN FOR A UTILITY-SCALE PV SYSTEM > 10 MW



SOURCE IEA PVPS.

FIGURE 6.8: UTILITY-SCALE SYSTEM HARDWARE COST BREAKDOWN



SOURCE IEA PVPS.

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 that 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 Levelised Cost of Electricity or LCOE) at a price below the price of electricity consumed from the grid. While this is valid for pure players (the so-called "grid price" refers to the price of electricity on the market), this is based on two assumptions for prosumers (producers who are also consumers of electricity):

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

However, it is assumed that the level of self-consumption that can be achieved with a system that provides up to the same amount of electricity as the local annual electricity consumption on a yearly basis, varies between less than 30% (residential applications) and 100% (for some industrial applications) depending on the country and the location.

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:

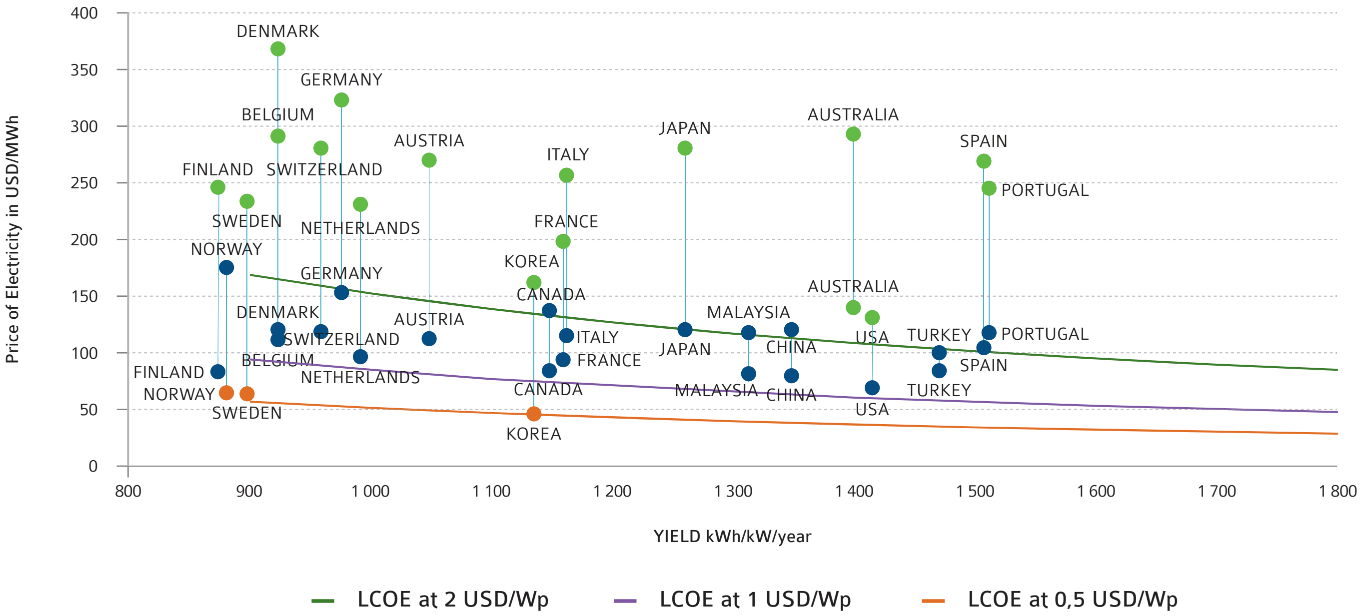
- The procurement price of electricity on electricity markets plus the margins of the reseller;
- Grid costs and fees, partially linked to the consumption, partially fixed; the key challenge is their future evolution;
- Taxes;
- Levies (used among other things to finance the incentives for some renewable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

If the electricity procurement price can be obviously 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 6.9 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. 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/Wp, converted into LCOE). Green dots are cases where PV is competitive in most of the cases. Orange dots show where it really depends on the system prices and the retail prices of electricity. Red dots are only competitive under very good conditions.

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.

FIGURE 6.9: LCOE OF PV ELECTRICITY AS A FUNCTION OF SOLAR IRRADIANCE & RETAIL PRICES IN KEY MARKETS*



*NOTE THE COUNTRY YIELD (SOLAR IRRADIANCE) HERE SHOWN MUST BE CONSIDERED AN AVERAGE.

SOURCE IEA PVPS & OTHERS.

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 2019 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 already 2019 electricity prices. Such business models remain however riskier than conventional ones that guarantee prices paid to the producer over 15 years or more.

The key risk associated with such business models lies in the evolution of wholesale market prices 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.

COST OF PV ELECTRICITY / CONTINUED

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.

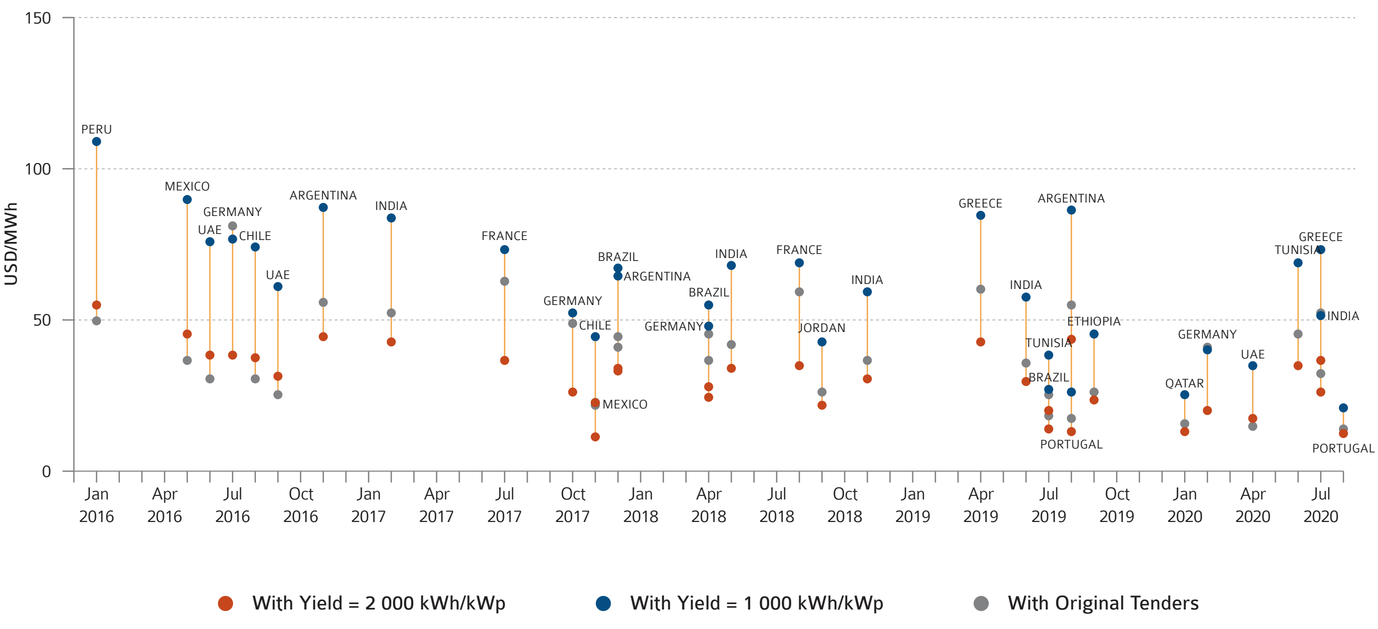
PRODUCING COMPETITIVE GREEN HYDROGEN WITH PV

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

With several countries having adopted tenders as a way to allocate PPAs to PV projects, the value of these PPAs achieved record low levels again in 2019. 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 0,6 USD/Wp) and a low cost of capital. At the moment of writing these lines, the latest records were 13,20 USD/MWh in Portugal, 13,53 USD/MWh in the United Arab Emirates and 14,49 USD/MWh for PV projects in Qatar to be built in the coming years, under specific conditions. Many other winning bids globally

FIGURE 6.10: NORMALIZED LCOE FOR SOLAR PV BASED ON RECENT PPA PRICES 2016 - Q3 2020



SOURCE IEA PVPS, BECQUEREL INSTITUTE.

TABLE 6.3: TOP 10 LOWEST WINNING BIDS IN PV TENDERS FOR UTILTY SCALE PV SYSTEMS

REGION	COUNTRY/STATE	USD/MWh	YEAR
EUROPE	PORTUGAL	13,2	2020
MIDDLE EAST	UAE	13,5	2020
MIDDLE EAST	QATAR	14,5	2020
EUROPE	PORTUGAL	16,6	2019
LATIN AMERICA	BRAZIL	17,5	2019
NORTH AMERICA	MEXICO	20,6	2017
LATIN AMERICA	CHILE	21,5	2017
MIDDLE EAST	UAE	24,2	2016
LATIN AMERICA	CHILE	24,4	2016
LATIN AMERICA	CHILE	24,4	2016

EURO exchange rate adapted in september 2020.
1 EURO = 1.12 USD

SOURCE IEA PVPS 8 OTHERS.

reached a level below 35 USD/MWh. Low PPAs were granted in 2019 in the USA but with the help of the 30% tax credit and accelerated 5-year tax depreciation. Beginning in 2020, the tax credits gradually decrease to 10% for commercially owned systems and expire for systems owned by individuals. In Europe, projects linked to tenders represent the most competitive PV installations and their share is growing as more and more market segments are shifting to this type of procurement. See Table 6.3 for a view of the top 10 most competitive tenders' prices. The tenders in Portugal seem significant below the levels of costs that PV could reach for the time being and indicate the rise of new business models which can also comprise bets on future wholesale prices developments.

COMMENTS ON GRID PARITY AND COMPETITIVENESS

Finally, the concept of Grid Parity remains an interesting benchmark but should not be considered as the moment when PV is competitive by itself in a given environment. On the contrary, it shows how complex the notion of competitiveness can be and how it should be treated with caution. Countries that are approaching competitiveness are experiencing such complexity: Many European countries have retail electricity prices that are above the LCOE of a PV system. However, considering the self-consumption and grid constraints, they have not reached competitiveness yet. For these reasons, the concept of Grid Parity should be used with caution and should take into consideration all necessary parameters. Finally, PV remains an investment like many others. The relatively high level of certainty during a long period of time should not hide the possible failures and incidents. Hedging such risks has a cost in terms of insurance and the expected return on investment should establish itself at a level that comprises both the low project risk (and therefore the low expected return) as well as hedging costs.

seven

PV IN THE ENERGY SECTOR

PV ELECTRICITY PRODUCTION

Tracking of PV Installed Capacity and Monitoring of PV Production

Tracking PV installations in all the regions of the world can be challenging as many countries do not accurately keep track of the PV systems installed or do not make the data publicly available.

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.

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 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.

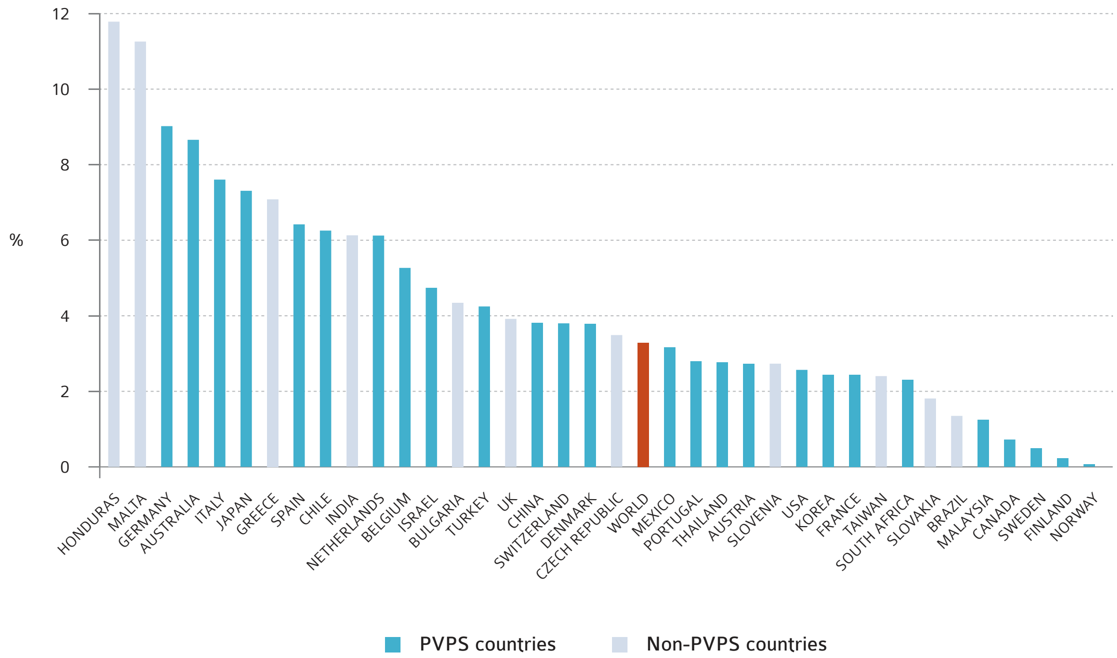
PV PENETRATION

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.

Figure 7.1 shows how PV theoretically contributes to the electricity demand in IEA PVPS countries and other major markets, based on the PV capacity at the end of 2019. Germany is the number one country in the IEA PVPS network with 9,0% of PV penetration based on the installed capacity at the end of 2019. Australia is following with 8,7%. Italy and Japan are next with respectively 7,6% and 7,3%. Spain reaches 6,4% and Chile 6,3%. The Netherlands are above the 6% mark with 6.1% PV penetration followed by Belgium with 4,9%. The last PVPS countries above the 3% mark are Israel (4,7%), Turkey (4,2%), Switzerland (3,8%), China (3,8%), Denmark (3,8%) and Mexico (3,2%).

Finally, Portugal, Thailand, Austria, United States, Korea, France, and South Africa are below the world average and below the 3% threshold, followed by Malaysia below the 2% threshold and by Canada, Sweden, Finland and Norway which are below the 1% threshold.

FIGURE 7.1: PV CONTRIBUTION TO THE ELECTRICITY DEMAND IN 2019



SOURCE SOURCE IEA PVPS & OTHERS.

PV PENETRATION / CONTINUED

TABLE 7.1: 2019 PV ELECTRICITY STATISTICS IN IEA PVPS COUNTRIES

COUNTRY	FINAL ELECTRICITY CONSUMPTION 2019	HABITANTS 2019	GDP 2019	SURFACE	AVERAGE YIELD	PV ANNUAL INSTALLED CAPACITY 2019	PV CUMULATIVE INSTALLED CAPACITY 2019	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	264	26	1 393	7 690 000	1 400	4 758	16 344	23	187	641	2	8.7%
AUSTRIA	65	9	446	84 000	1 050	247	1 702	2	28	193	20	2.7%
BELGIUM	85	11	530	33 688	925	587	4 861	4	51	423	144	4.9%
CANADA	540	38	1 736	9 985 000	1 150	232	3 326	4	6	88	0	0.7%
CHILE	73	19	282	756 096	1 699	288	2 694	5	15	142	4	6.3%
CHINA	7 230	1 400	14 343	9 634 000	1 350	30 100	205 242	277	22	147	21	3.8%
DENMARK	33	6	348	44 000	925	109	1 362	1	19	234	31	3.8%
FINLAND	86	6	269	390 908	875	81	214	0	14	38	1	0.2%
FRANCE	473	67	2 716	543 965	1 160	966	9 934	12	14	148	18	2.4%
GERMANY	531	83	3 846	357 170	978	3 835	49 016	48	46	590	137	9.0%
ISRAEL	73	9	395	22 070	1 797	556	1 914	3	61	211	87	4.7%
ITALY	320	60	2 001	301 336	1 164	758	20 865	24	13	346	69	7.6%
JAPAN	906	126	5 082	377 962	1 050	7 031	63 192	66	56	500	167	7.3%
KOREA	520	52	1 642	100 401	1 137	3 130	11 229	13	60	217	112	2.5%
MALAYSIA	149	33	365	330 621	1 314	499	1 417	2	15	43	4	1.3%
MEXICO	270	128	1 258	1 964 380	1 708	1 926	5 001	9	15	39	3	3.2%
NETHERLANDS	111	17	909	41 500	994	2 352	6 874	7	136	397	166	6.1%
NORWAY	135	5	403	385 178	882	51	118	0	10	22	0	0.1%
PORTUGAL	47	10	238	92 220	1 600	155	827	1	15	81	9	2.8%
SPAIN	269	47	1 394	505 940	1 745	4 751	9 910	17	101	211	20	6.4%
SWEDEN	132	10	531	407 284	900	291	720	1	28	69	2	0.5%
SWITZERLAND	58	9	703	41 285	980	325	2 498	2	38	291	61	4.3%
SOUTH AFRICA	193	59	351	1 219 090	1 733	151	2 560	4	3	44	2	2.3%
THAILAND	194	70	544	1 219 092	1 522	16	3 529	5	0	51	3	2.8%
TURKEY	303	83	754	783 560	1 500	1 398	8 547	13	17	102	11	4.2%
USA	4 153	329	21 428	9 147 282	1 416	13 272	75 770	107	40	230	8	2.6%
WORLD	24 700	7 674	87 752	134 325 435	1 300	111 585	623 234	810	15	81	5	3.3%

Outside the IEA PVPS network, Honduras is taking the lead with 11,8%, followed by the islands of Malta with 11,3%. Greece ranks third with 7,1% in 2019. India reached 6,1%, Bulgaria 4,4%, followed by UK (3,9%) and Czech Republic (3,5%).

Many other countries have lower production numbers, but in total 33 countries produced at least 1% of their electricity demand from PV in 2019.

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. 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 623,2 GW installed worldwide, PV could produce more than 810 TWh (see Table 7.1) of electricity on a yearly basis. With the world's electricity consumption of 24 700 TWh in 2019, this represents around 3,3% of the global electricity demand covered by PV as presented in Figure 7.2. Performances losses due to aging of PV plants are not considered at this point.

Figure 7.3 shows the newly installed renewable capacity in 2019. Solar PV was the top source of new power generating capacity in 2019. For the fourth year in a row, newly installed renewable energy sources outpaced net additions of fossil fuels and nuclear power combined[5] and accounted for 72% of all power expansion.

In 2019, PV represented 63% of the world's newly installed capacity of renewables, excluding hydropower. Wind power represented 33% with 60,4 GW installed.

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 allow 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.

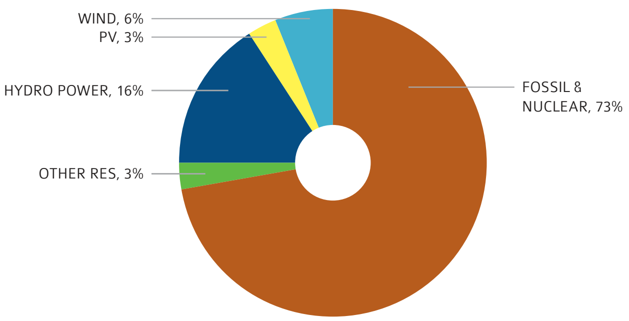
Australia kept its place as a leading country for batteries with some large-scale installations, the market reached over 2,7 GWh cumulative installation and is expected to achieve a staggering 12,9 GWh of cumulative storage deployments over the next five years. Next are the United States with 1 GW installed at the end of 2019, only a small part of the nation's cumulative solar generation capacity equipped with battery storage. However, this number is expected to double between 2020 and 2022. In Germany, the 200 000 installations threshold was reached at the end of 2019, with over 65 000 new rooftop-PV linked storage systems in 2019 only.

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, HEATING AND COOLING

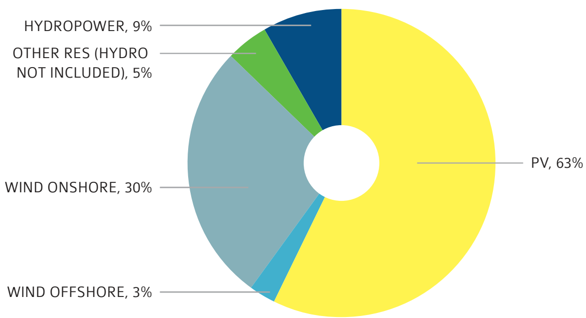
The decarbonation of the energy sector will require electricity to become the main vector for applications that used to consume fossil fuels, directly or indirectly. In this respect, the development of solar heating and cooling hasn't experienced major developments in 2019, contrary to electric mobility that starts to develop quickly in several countries: The market is expected to take off in China, as 12% of all cars sold in China in 2020 should be fully electric or plug-in hybrids. The Chinese government also intends to establish national supply chains for hydrogen generation and fuel cell vehicles for 2024.

FIGURE 7.2: SHARE OF RENEWABLE IN THE GLOBAL ELECTRICITY PRODUCTION IN 2019



SOURCE REN21, IEA PVPS.

FIGURE 7.3: NEW RENEWABLE INSTALLED CAPACITY IN 2019



SOURCE REN21, IEA PVPS.

5 Source: R*EN21Global Status Report.*

PV INTEGRATION AND SECTOR COUPLING / CONTINUED

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

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. 2018 and 2019 showed announcements from several manufacturers, especially in Japan and Korea, but also Germany and the Netherlands, for VIPV systems integrated in EVs. The IEA PVPS Task 17 deals with this fast-emerging subject.

A growing number of countries and cities have announced partial or total banning of internal combustion engines, often for a combination of climate targets and air quality measures. Amongst the early adopter of such plans, Canada, France and Sri Lanka have announced that fossil-fuelled cars will be banned from the market from 2040, while Norway is more ambitious and is aiming for 2025 through tax and usage incentives. Other countries followed, such as Iceland, Ireland, Israel, the Netherlands, Slovenia with proposed introduction of the measures in 2030. The only countries to implement total bans on internal combustion engines are the Netherlands, Singapore and Sri Lanka.

The Government of China and Korea have announced plans to expand the domestic production of eco-friendly vehicles. In Korea, the cumulative target is of 430 0000 EVs and 65 000 hydrogen fuel cell vehicles by 2022. To achieve these goals, the obligatory purchase percentage of eco-friendly vehicles by public entities will rise to 100% by 2020 and 2 000 hydrogen buses will be deployed by 2022. Charging infrastructures for EVs and hydrogen fuel cell cars will be prepared by local governments with support from the central government.

With more than 2 million electric vehicles sold in the world in 2019, the automotive sector is moving rapidly towards the electricity industry and most automotive manufacturers have announced plans to expand their portfolio of electric-powered vehicles.

Another remarkable trend concerning electric mobility is the rise of electric two wheelers. In Germany, 40 000 electric cargo-bikes were sold in 2018. E-bike popularity has been growing recently in some European countries, where they represent a clean and efficient alternative to four-wheel transport not just by privates but also professionals. Whereas in Asian countries, e-scooters have been more successful and are expected to further lead the EV market.

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.

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.

For instance, in France, some electric utilities are more and more interested in partially converting the nearly 15 TWh used yearly during night to heat domestic hot water into usable thermal energy storage for green electricity. The challenge is even more pressing in the short term for non-interconnected territories such as Corsica and overseas territories.

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.

PV COMMUNITIES AND COLLECTIVE SELF-CONSUMPTION MODELS

The concept of collective/delocalized self-consumption allows to create additional value for both producers and consumers through a virtual metering, based on a transfer of excess energy between participating consumers. Grid operators should benefit from collective self-consumption as well as the consumption should be more synchronized with the production.

The European definitions provide a good starting point to discuss the development potential of different models of collective self-consumption models:

- Citizen Energy Community (CEC) which focusses on electricity and the level playing field on the market,
- Renewable Energy Community (REC) which only includes renewable energy sources and is limited to members located in the proximity of the renewable assets,
- Jointly acting renewables self-consumers which focus on the share of renewable electricity within the same building or multi-apartment block.

In practice, emerging PV communities and collective self-consumption initiatives can often be attributed to one of these three definitions; however, mixed models also exist. Nonetheless, the distinction between both models provide a good basis to discuss the opportunities, constraints, and advantages of collective self-consumption.

In the case of collective self-consumption driven by a group of prosumers, in a limited geographical area (REC), the main goal might be to increase the local self-consumption and the local penetration of renewables through local storage and demand side management. This energy consumed locally could be (partially or completely) exonerated from transport grid costs to allow increasing the value of locally generated and used electricity. This could be applied to a range of situations, from apartment owners with a collective rooftop PV system to a neighbourhood with multiple PV prosumers.

In the case of collective self-consumption with a focus on electricity exchanges, the proximity of the consumers is not a prerequisite anymore. Therefore, the main objective is to optimize the overall production and consumption profile to benefit from better electricity prices or to deliver grid services such as balancing. The opportunities opened by such concepts range from charging an electric vehicle in a distant location with PV electricity produced at home, to installing a utility-scale plant to power several buildings. Using PV electricity in a geographically distant location implies the use of the distribution or even transmission grid and would require putting a fair price on such use.

If both models allow to activate the distributed flexibility potential, smart digital tools will often be a prerequisite to avoid response fatigue in the long term and even more so to insure the delivery of reliable grid services. Most of the energy consumption and the potential for load management of households is related to transport and heating, there also digital tools will be essential to provide load shifting without loss of comfort.

ELECTRIC UTILITIES INVOLVEMENT IN PV

In this section, the word "Utilities" will be used to qualify electricity producers and retailers, not the grid management activities. In some parts of the world, especially in Europe, the management of the electricity network is now separated from the electricity generation and selling business. This section will then focus on the role of electricity producers and retailers in developing the PV market.

In Austria, many electricity utilities started public participation models for PV, others are selling PV systems. The electric cars development might further push PV, since many utilities offer EV services and install charging stations; thus the direct link to the use of electricity out of renewables is visible. Nearly all larger utilities are meanwhile promoting PV for private houses, industries or multifamily solutions. Because of the ambitious governmental plans to add another 11 GW to the existing 1,7 GW until 2030, many electricity companies are currently planning very large PV systems in the multi MW range.

In Denmark many utilities introduced PV technology in their portfolio and selling systems. Now when the marked is more mature and competitive the utilities have made marked exit. They are now developing larger utility scale projects for their own RE portfolio.

ELECTRIC UTILITIES INVOLVEMENT IN PV / CONTINUED

In Finland, several utility companies have started to sell and install turnkey PV systems as a product for residential houses and commercial buildings. They either make the installations by themselves or have contracts with installation companies. In June 2017, most utility companies have announced offers to buy surplus electricity from micro-PV plants. In general, the utilities pay the Nord Pool Spot Finland area price of the surplus electricity without VAT 24%, which is roughly one-third of the retail electricity price.

In France, EDF and ENGIE are both major international players, with a large international portfolio covering both fossil (and nuclear) and renewable energies. There are no legal or regulatory barriers to their active involvement in photovoltaics generation in France, although EDF must demonstrate a complete separation of its public service delegations (network management, electricity contracts on government regulated prices) and commercial activities. EDF Renouvelables (EDF Renewable for the international branch), a subsidiary of EDF, EDF Renouvelables Services (O&M services in Europe), and EDF Energie Nouvelles Réparties (EDF ENR), its own subsidiary, are all active in France. EDF ENR is active in the residential market. A second subsidiary company, EDF EN Photowatt, is a photovoltaics manufacturer. EDF is also active in R&D activities through both EDF internal research departments, research partnerships with public research organisations and Photowatt. Local authorities deploy mandatory and voluntary climate action plans and ambitious photovoltaics goals are becoming frequent. Furthermore, investment on infrastructure belonging to local authorities is accelerating, either through direct investment or by third party investment (commercial, private-public investment vehicles or citizen-led).

In Germany, energy companies such as E.ON and RWE, listed in the top five leaders affecting the electricity market and production, have recently signed a transaction agreement according to which they are creating two focused European energy companies. E.ON plans to acquire RWE’s stake in Innogy in return and aims at becoming a game changer in the decentralized energy world while RWE will work to become one of the European leaders for renewable energy and security supply. They are developing new innovative solutions for the PV market to target PV on rooftop customers (e.g. Google Sunroof, E.ON SolarCloud, E.ON Aura solar systems) providing PV and storage-based solution for end-consumers.

In Sweden, several utility companies started in 2012 to market small turnkey PV systems suited for roofs of residential houses. These utility companies have in common that most of them collaborate with local Swedish installation companies that provide the actual system and execute the installation. Only a few of them have the installation competence and product distribution lines in-house. One utility company, Umeå Energi also offer leasing of PV system to private persons. Furthermore, in 2011, several utility companies started introducing compensation schemes for buying the excess electricity produced by micro-producers. This trend continues, and more and more utility companies now have various offers for the micro-producer's excess electricity, their green electricity certificates and guarantees of origin.

A few utilities have started to work with centralized PV parks. Since there are no subsidies for large-scale PV parks in Sweden, except for the green electricity certificate system and some direct capital subsidies, the utility companies had to test different financial arrangements and business models such as share-owned PV parks, power purchase agreements and PV electricity offers to end consumers.

In Switzerland, an increasing number of electricity utilities are entering the PV business. Especially the larger utilities who have their own non-solar electricity production facilities, have been under increasing financial pressure, due to falling electricity prices on the European market, and are therefore expanding their business activities. Due to the private-public status of most of the utilities (they are typically owned by the communities and the cantons) this development is not always viewed positively by the incumbent PV installation companies.

In Japan, following full liberalization of electricity retailing in 2016, new players entered electricity retailing business one after another. The number of registered electric retailers was 619 (as of December 2019) and these Power Producers and Suppliers (PPS) and the former General Electricity Utilities that used to conduct regional monopolistic business are competing in the electricity market. Although the share of PPS increased to 16,2% (as of December 2019), the situation of the electricity market in which former General Electricity Utilities are dominant remains unchanged and the same situation is observed in the power generation sector. The share of trading quantity on the Japan Electric Power Exchange (JEPX) rose to 39,5% (as of December 2019). The effects of gross bidding, etc. by former General Electricity Utilities to revitalize the trading have been observed. As a final phase of the Electricity System Reform, legal separation of the power transmission sector and the power distribution sector of the former General Electricity Utilities was carried out by April 2020. Accordingly, some electric utilities were preparing for the separation of power transmission and distribution business as separate companies.

In Malaysia, behind-the-meter PV businesses enables PV investors to provide leasing or PPA services to customers who do not wish to go for an outright purchase option. Under the leasing or PPA model, counterparty risks exist when customers do not pay to the PV investors. The national utility came up with an innovative package to provide billing, collection, and remittance services to PV investors by including the billing of the PV investors in the prosumers' monthly electricity bills. Additionally, SARE provides deed of assignments to allow the payment collected from customers to be channelled to financial institutions that financed the PV investors’ projects. Under the SARE, TNB, the PV investor and the customer entered into a tripartite agreement and with TNB on board, the project is attractive to the financial institutions as the PPA is bankable and this is helpful for the small medium enterprises/industries.

In China in March 2019, the National Energy Administration issued the "Pilot Work on Further Promoting the Construction of Power Spot Market. The Exposure Draft proposed to establish a spot trading mechanism to promote clean energy consumption. In the initial stage of the spot market operation, clean energy can be used to participate in the spot market transactions by means of put forward volume without quotation, priority is given to clean energy as a price recipient to clearing out and achieve priority consumption. In 2019, all six provincial-level power spot market pilots in the State Grid’s operating areas have started trial operation to encourage new energy to participate in the market and take advantage of low marginal costs to achieve consumption. In August, all eight provincial-level power spot markets were put into trial operation.

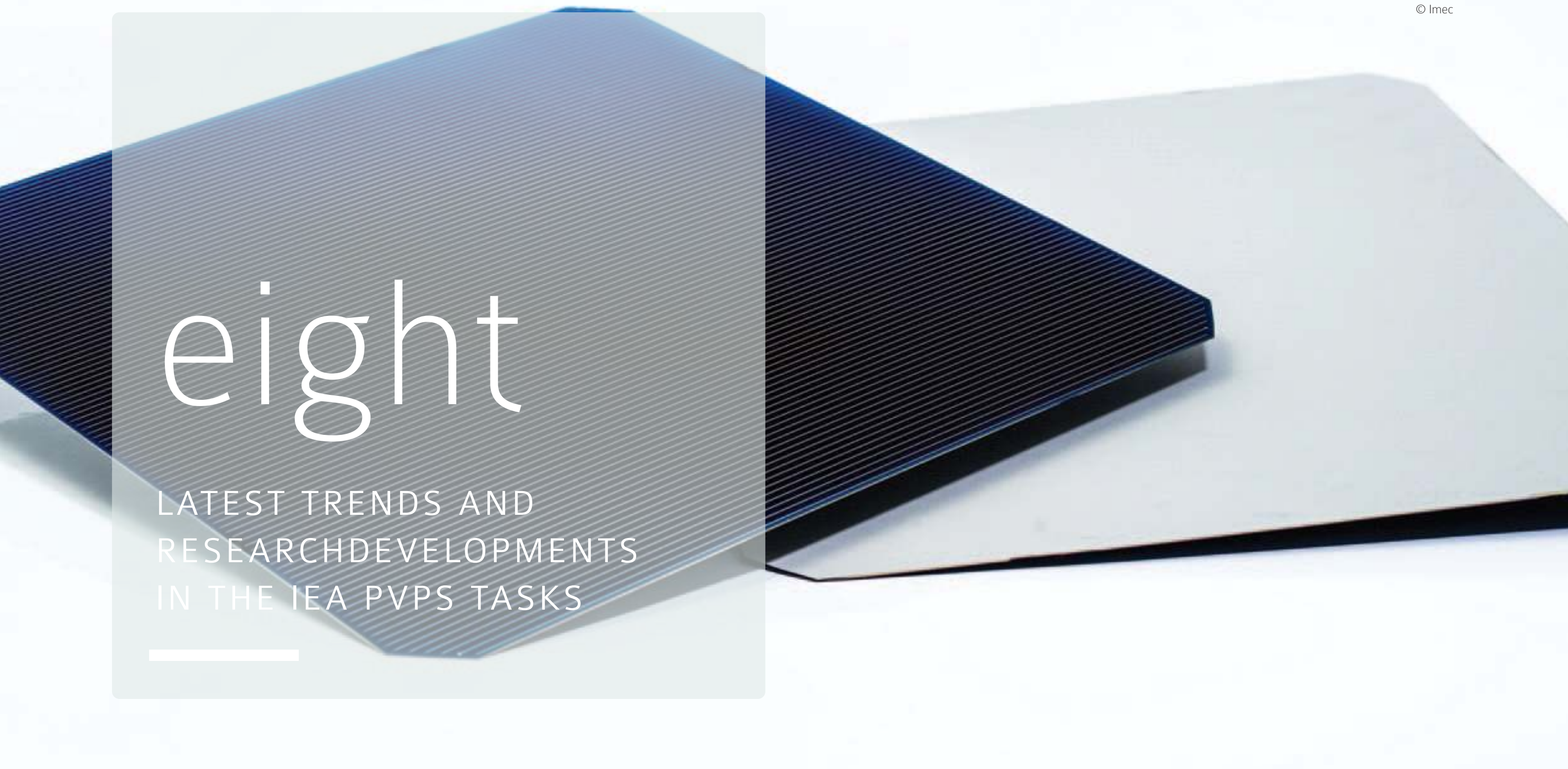
In Canada, given the diversity in market structures, the interest from electricity utility businesses is equally variable. In general, many utilities offer lease-to-own programs.

The USA have a diverse deregulated utility landscape in which roughly 68% of consumers are served by an investor owned utility and the remaining customers are served by municipal utilities or cooperatives. Utilities are regulated at the local, state, and federal level by PUCs, ratepayer groups and federal agencies such as the Federal Energy Regulatory Commission (FERC) to ensure they provide fair and reliable service to their customers. Transmission is regulated by Independent System Operators (ISO) or Regional Transmission Organizations, depending on region. Electricity utility interest in solar continues to increase in the United States. As utility scale solar has become increasingly competitive with retail generation, four broad categories of utility solar business models have emerged in the United States: utility ownership of assets, utility financing of assets, development of customer programs, and utility purchase of solar output

In Australia, the businesses that make up the electricity industry have collectively recognised the inevitability of solar power rolling out across Australia, and most have opted to play a constructive role.

Solar is impacting the energy market operation both technically and financially. Financially, PV is reducing the amount of energy transported and sold, thereby impacting revenues of the grid operators and the energy suppliers. PV is also introducing more volatility on the wholesale electricity prices both reducing the price on sunny days and increasing the price when not available when demand is peaking. Price volatility is needed to create the market incentives to develop flexibility and storage for instance. Technical issues most commonly relate to local grid congestion and to inverter response to system disturbance and impacts upon local voltages.

In addition to conventional utilities, PV developers could be the utilities of tomorrow, developing, operating and trading PV electricity on the markets. Many newly created companies have succeeded in developing impressive renewable energy portfolios over the years. Thereby, renewable energy and most particularly PV are reshuffling the distribution between historical and emerging actors.



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LATEST TRENDS AND RESEARCHDEVELOPMENTS IN THE IEA PVPS TASKS

TASK 12: STATUS OF C-SI PV RECYCLING IN SELECT WORLD REGIONS

EUROPE

Europe is the only continent with dedicated c-Si PV recycling facilities operating commercially, as of early 2019. (Cadmium telluride (CdTe) thin film PV modules have been recycled at commercial scale for over 10 years, reaching nearly 4 500 tonne in 2017 (First Solar, 2018).) The largest facility, in France, currently can mechanically process 1 300 tonne/yr, with planned expansion to 4 000 tonne/yr in 2022 (Veolia, 2018). Another PV-dedicated recycling facility is under development in Germany and is expected to use pyrolysis with a combination of mechanical and electrochemical processes to achieve 90% total mass recovery, including trace metals (Suez, 2018). Its announced scale is approximately 137 modules/day. Both facilities received funding for process development from the European Commission. Meanwhile, statistics about EoL modules are being collected and reported in several countries (Table 8.1). Most PV modules recycled in Europe today are run in batches through existing glass or metal recycling lines (Wambach et al., 2017).

JAPAN

Twenty-three companies have been listed as accepting and “properly treating” PV modules in Japan (JPEA, 2019). However, only one of these companies specializes in recycling PV modules, though its process is limited to detaching the frames and separating front glass from the back sheet and it has processed approximately 32 500 modules through February 2019 (PVTechnoCycle, 2019; NPC Incorporated, 2019). The other companies are intermediate processors of more common kinds of industrial waste (e-waste, cars, etc.) whose main function is to separate bulk materials and send them to more specialized recyclers (e.g., of metals, glass). Almost all these companies use a mechanical approach such as shredding and sorting and do not use specialized equipment for PV modules. Currently, silicon is not a target for recovery because of low value in the Japanese market. The Japanese government estimates that 4 400 tonne/yr of PV waste are generated currently (Japanese Ministry of Environment, 2018), which is projected to rise to 170 000–280 000 tonne/yr by the middle 2030s (METI, 2019).

TABLE 8.1: COLLECTION OF END OF LIFE PV MODULES FROM SELECTED EUROPEAN COUNTRIES

	2015	2016	2017	2018	2019	SOURCE
Germany	n/a	2 032	3 595	7 865	n/a	Eurostat (2020)
United Kingdom	95	99	107	86	65	UK Environment Agency (2020)
France	0	0	84	3 341	4 753	ADEME (2020)

UNITED STATES OF AMERICA

Currently, the USA lacks recyclers, policies, incentives, and regulatory drivers specific to PV recycling at state (except for Washington (Washington State Legislature, 2017)) and national scales. Voluntary efforts have emerged to fill the gap. The Solar Energy Industry Association's (SEIA's) National PV Recycling Program (SEIA, 2019) lists six US firms capable of recycling modules and inverters; five will accept c-Si modules, and one recycles its own thin-film modules. The more active c-Si recyclers in SEIA's program report receiving and processing a total of approximately 100 tonnes per month (SEIA, 2019). (CdTe PV module recycling, by contrast, has been performed at commercial scale for more than 10 years, reaching 4 050 tonnes recycled in 2017 (First Solar, 2018)). Owing to the low volumes of modules being sent for recycling, recycling lines dedicated to c-Si PV modules have not been developed in the US; c-Si module recycling now occurs on existing glass, metal, or e-waste product lines, in batches when a sufficient module volume is obtained by the recycler (EPRI, 2018b; Wambach et al. 2017). Existing recyclers seek specific materials that are best tied to current business models, flows, and capital assets. Consequently, recovery of materials by the recyclers listed in SEIA's program focuses on materials that can be separated and sold without extensive processing, like glass and bulk metal; unwanted materials are moved to other recyclers (Butler, 2019).

An empirical estimate of total US EoL PV modules is unavailable, but recycled modules likely represent only a small fraction. Based on anecdotal reports, some modules are being disposed of in municipal (nonhazardous) and hazardous landfills. Others are being stored until lower-cost and easier recycling options develop, accumulated quantities become more economical to ship and recycle, and issues such as testing for hazardous waste determination (toxic contaminant leach testing)—which affect interstate transport and treatment options and costs—are resolved (EPRI 2018b; California Product Stewardship Council, 2019).

TASK 13: CALCULATION OF PERFORMANCE LOSS RATES: DATA QUALITY, BENCHMARKS AND TRENDS

The calculation of the evolution of a PV system performance is crucial to i) evaluate if a system is operating within the boundaries of long-term yield assessment and warranties and ii) provide more accurate values to be used in yield assessments not only in terms of absolute value but also in terms of uncertainty. In order to be able to judge a system performance, the performance loss (PL) must be calculated in an accurate and well documented way and uncertainty provided. Data availability, accuracy and resolution have to be taken into account when choosing and carrying out the necessary steps to calculate PL values. 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.

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 (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 calculation of PLR 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: i) use of shared methodologies on shared time series, ii) use of confidential methodologies on shared time series, iii) use of shared methodologies on confidential time series. The data is used for benchmarking activities and to define which methodologies clusters around a "true value" of PLR. The combination of metrics (PR or power based) and methodologies are benchmarked in terms of deviation from the average value and in terms of standard deviation. The combination of temperature corrected PR with the use of Year on Year or STL performs very well compared to others.

Another set of data is represented by the IEA PVPS Task 13 "PV Performance Database" which includes more than 120 PV plants from different climates. These data are considered of low quality as there is no confirmed quality check and the time resolution of energy and insolation is monthly; nominal power and the type of solarimeter is also given by external users. Two methodologies were applied, Seasonal and Trend decomposition using Loess (STL) and Year on Year (YoY), and the PLRs were analyzed in terms of PV technology and climate. STL results in an averaged PLR over all systems of -0,78%/a, while YoY yields -0,63%/a. STL is better suited if the time series data are of higher resolution and high-quality weather data are available.

Additionally, PL values of the datasets were divided into different technologies and Köppen-Geiger climate zones. As expected, thin-film systems experienced by far the highest PL of almost -1%/year in average. Both, mono- and poly-crystalline silicon systems were subject to lower losses of -0,5 to -0,7%/year, values which are additionally confirmed compared to previous studies. It was also visible that the climatic conditions affect the PL over time. High temperatures seem to have an especially severe effect. Comparing similar climate zones, which differ from one another mainly in humidity, did not suggest a proportional relationship between degradation and increasing humidity. Further studies in this regard must be carried out to confirm this hypothesis, also including climate zones in extreme humid conditions.

One important outcome of this study is the contribution to a clear and structured quality classification for PV time series data and a guideline for PLR calculations in dependency of the data categorization.

TASK 14: SOLAR PV IN A FUTURE 100% RES BASED POWER SYSTEM

Following the massive deployment of PV and other variable renewable energy sources (RES) – particularly wind – "high penetration" of solar PV is no longer a local "distribution grid" issue that is limited to few regions or countries. Instead, we are increasingly seeing "RES dominated" grids, where variable generation from RES reaches levels in the order of magnitude of the load even at the transmission system level. This substantial transition of the power systems in numerous countries and regions brings several new technical as well as non-technical challenges. Starting with efficient solutions for the integration of power generation embedded in local distribution grids, interaction and sharing ancillary service provision between distribution and transmission system and finally managing wide-scale interconnected power systems with a large supply from variable sources. With solar PV becoming the least-cost option for bulk power supply in more and more regions of the world, the integration into the power systems and their management will be the key to ensure an appropriate role and enable further deployment.

The following trends highlight the developments in 2019:

- **From Solar PV in the Distribution Grids towards 100% RES Supplied Power Systems**

  With increasing share of power supply coming from the distribution system, also the provision of ancillary services from the distribution to the transmission systems and more widely the interaction between the (mostly unbundled) operators of the two systems becomes vital to enable an efficient operation of the power system. Today it has become clear that solar PV related integration questions, particularly related to system-wide issues have to be addressed together with other variable renewable energy sources. As part of the collaboration between IEA PVPS Task 14 and IEA WIND Task 25 ("Design and Operation of Power Systems with Large Amounts of Wind Power") a joint "Expert Group Report on Recommended Practice for Wind/PV Integration Studies" addressed these aspects and presented a best practice for performing solar PV and wind grid integration studies.

- **New Grid Code Requirements Maintain Stability and Increasing Resilience in Power Systems**

  The increasing share of static converter-based generation (PV and wind) and a simultaneous decline of system inertia today provided almost exclusively by synchronous rotating generators, has further increased concerns about overall system stability and a general change in system behaviour during critical situations.

  In Europe, this fact has led to the establishment of European-wide "Network Codes", covering different aspects of the interconnected European electricity system. For solar PV, the Network Code on Requirements for Generators, already led to a significant development in the national interconnection codes. These new requirements for all generators which started to be implemented in April 2019, aim to ensure system stability with increasing share of variable generation and market driven power flows.

  In the USA, the IEEE 1547 standard, defining the main requirements for the interconnection of distributed generators has been published in 2018, following a fundamental revision of its scope and approach. The new definitions now introduce comprehensive requirements for ride-through capabilities, grid support functions as well as communication and control features to be provided by all new distributed generators, not limited to solar PV or wind.

- **The Smart Grid is Becoming Reality**

  While still at the beginning, implementation of Smart Grid concepts in power systems worldwide are becoming a widespread option to address challenges of managing power systems, especially balancing load and demand with an increasingly decentralised supply and new components being connected to the more and more constrained grids, such as storage systems, flexible customers, intelligent buildings or electric vehicles.

  For solar PV, a future Smart Grid can enable a wide range of additional services, provision of flexibility, enable local supply as well as the delivery of ancillary services. However, there are numerous questions to be answered to ensure a sustainable role for PV in this changing environment. Individual technologies for smart grid solutions are already available today. Now these technologies have to be more widely integrated into distribution grids, systematically linked together, and optimised.

  Task 14 has been supporting different stakeholders from research, manufacturing as well as electricity industry and utilities by providing access to comprehensive international studies and experiences with a dedicated focus on technical issues related to the role of solar PV in a future 100% RES based power system.

TASK 15: ENABLING FRAMEWORK FOR THE ACCELERATION OF BIPV

The building sector is responsible for 36% of global end-use energy consumption and nearly 40% of total direct and indirect CO_2 emissions. Goals and specific targets have been set up globally to reduce the environmental impact of the built environment. Political statements and directives have been moving further towards zero-energy buildings, communities and cities. PV systems play a significant role in this development. Since the start of the first phase of IEA PVPS Task 15 in 2015, the prices for PV components and readily installed conventional PV systems have been drastically reduced improving the possibility for integrating photovoltaic components into other products like building components. Several studies emphasized the large share of PV in future renewable energy systems and further studies revealed the large technical and economic potential of building skins for photovoltaic energy conversion.

In summary, all these boundary conditions create a very promising background for BIPV market uptake. However, a major fraction of the potential remains unused. The presence of (1) proven technology, (2) numerous successful examples, (3) new innovative BIPV products with a larger degree of design freedom for architects and (4) an increasing need for energy conversion at the building level, is still not sufficient to foster a large and self-sustaining BIPV market. There are still hurdles for large-scale market penetration of BIPV, both at national and international level. These hurdles consist especially of economic, technological, legal, aesthetic, reliability and normative issues. There is still a strong need for knowledge transfer between BIPV stakeholders, a missing link in business approach, an unequal playing field regarding regulatory issues and environmental assessment and a transfer gap between products and application.

Task 15 will address these issues by exchanging research, knowledge and experience, and offering the possibility to close gaps between all BIPV stakeholders, creating an enabling framework to accelerate the implementation of BIPV. Thus, Task 15 aims at helping stakeholders from the building sector, energy sector, the public, government and financial sector to overcome technical and non-technical barriers in the implementation of BIPV in the built environment by the development of processes, methods and tools that assist them.

Within Task 15 it is aimed to create an enabling framework to accelerate the penetration of BIPV products in the global market of renewables, resulting in an equal playing field for BIPV products, BAPV products and regular building envelope components, respecting especially economic, technological, legal, aesthetic, reliability and normative issues. To address these topics, the experts have developed the following subtasks:

- A: Technical Innovation System (TIS) Analysis for BIPV
- B: Cross-sectional analysis: learning from existing BIPV installations
- C: BIPV Guidelines
- D: Digitalization for BIPV
- E:Pre-normative international research on BIPV characterisation methods

This Task contributes to the ambition of realizing zero-energy buildings and built environments. The scope of this Task covers new and existing buildings, different PV technologies, different applications, as well as scale differences from single-family dwellings to large-scale BIPV applications in offices and industrial buildings. Starting from the status quo in 2019, there is still a number of issues and the subtasks of Task 15 are tailored to make a major contribution to overcome these issues and accelerate the whole BIPV market towards the future vision: The widespread knowledge about BIPV enables all stakeholders to realize architectonically appealing BIPV systems that are economically rewarding, well planned -constructed and -operated with support of digital methods, based on a clear normative framework and thus strongly contribute to a renewable energy system and buildings with a small environmental footprint.

TASK 16: STATE OF THE ART FOR SOLAR RESOURCE ASSESSMENTS AND FORECASTS

Task 16 deals with historical solar resource data as well as forecasting for the next few days. Since the Task 16 started (mid 2017) no new reports about those topics have been published. However, the precursor Task 46 (of IEA SHC) and also IEA PVPS Task 14 published reports about state-of-the-art methods. Common guidelines are given in the solar resource handbook – the main output of Task 46.[6] This report will be updated by end of 2020 the by Task 16.

SOLAR RESOURCE ASSESSMENTS

The amount of work needed for resource assessments depend on the size of the PV installation. Less uncertainty lowers financial uncertainty and therefore costs. The more money is involved the more the uncertainty of resource data plays a role. However, there are limits to know: even in best cases with 20 years of solar radiation measurements uncertainties of less than 2% are almost impossible to achieve. Additionally, climate change and decadal variation of climate induce variabilities that are almost impossible to foresee.

For small to medium sized systems the use of monthly averages of the last 10-20 years or typical meteorological years are common. Often such data are directly included in PV simulation tools. Global radiation on horizontal and plane of array are needed. For bigger projects (approx. > 100 MW) time series of satellite data or ground data (if available nearby – which is seldom) are used. For projects above 500 MW involving important financial investments often local measurements for one year (with high quality equipment and regular calibration and maintenance) combined with long term satellite data are common. For the adaptation of the local short-term measurements to the long-term data different methods exists – the team of Task 16 currently is writing a paper about this topic. Methods include linear regressions and quantile mapping of distributions. In order to better serve the results (to be published 2020 in a peer-reviewed journal paper), no clear winning method will be shown.

6 https://www.nrel.gov/docs/fy08osti/43156.pdf

TASK 16: STATE OF THE ART FOR SOLAR RESOURCE ASSESSMENTS AND FORECASTS / CONTINUED

Additional meteorological parameters are also important. For small scale projects, at least the temperature is needed. For bigger projects precipitation, humidity, wind, albedo, soiling and snow conditions should be known.

SOLAR FORECASTS

The method to be used for solar forecasts depends on the time horizon of the forecasts. In the range of minutes either persistence (the radiation is taken as constant), stochastic models or all sky cameras are used. The uncertainties of those cameras are highly uncertain – the reason Task 16 is currently undertaking a benchmark.

For the time horizon of half an hour to four hours forecasts based on satellite images are standard. Several consecutive images are analysed, and cloud vectors detected (if not taken from forecast models). Those vectors are used to forecast the clouds and solar radiation in future. For a time horizon larger than six hours, numerical weather prediction models are best. As cloud position can't be forecasted exactly – the atmosphere is a chaotic system – probabilistic forecasts or at least combinations of different models are adequate. Post-corrections of forecasts are also needed as most prediction models show biased results.

Optimized forecast systems include a mixture of all three-time horizons.

BENCHMARK OF ALL SKY IMAGERS

All sky imagers (ASI) (also called cloud or sky cameras) are used for solar radiation forecasts for quite a few years now. Global radiation as well as direct radiation is forecasted for the upcoming 10-15 minutes in spatially and temporally high resolution. The development is in an early stage and most systems are developed in universities. There are only a few commercial systems available and many different methods to calculate the forecasts.

TASK 17: PV FOR TRANSPORT

In order to reduce greenhouse gas emissions from cars, initiatives aiming at a rapid rollout of electric vehicles (EV) and plug-in hybrid vehicles (PHV) have begun in countries across the world. In response to this situation, PV-powered vehicles are getting attentions as possible applications, and various activities and projects have been implemented in some countries.

In Japan, NEDO and Sharp Corporation announced on 6th July 2020 that they developed the second demonstration PV-powered passenger car. The car equipped with high-efficiency PV cells is an electric vehicle, 'e-NV200', manufactured by Nissan Motor Corporation, and the PV capacity is 1 150 W. They are planning to commence public road trials aiming to assess the effectiveness of improvements in cruising range and fuel efficiency of PV-powered vehicles, as well as the first demonstration PV-powered vehicle, TOYOTA Prius-PHV with 860 W PV cells developed in 2019. The goal of demonstrative project is to contribute to the creation of a new PV market, including the transport sector, and find solutions for energy and environmental issues.

Apart from the demonstration projects above, Kaneka Corporation, Japan, announced that crystalline silicon photovoltaic modules (heterojunction back-contact-type) they developed and designed in a curved shape have been adopted for use in the roof glass of Toyota Motor Corporation's low-speed automatic driving EV 'e-Palette' . They will continue to strengthen its photovoltaic module offerings for vehicles, which contribute to having longer driving distances and reducing CO_2 emissions, and aim to have them further adopted in EVs and hybrid cars.

In the Netherlands, it was announced in June 2020 that the Dutch solar car manufacturer Lightyear, put two research vehicles on the road, a Tesla Model 3 and a VW Crafter van with aftermarket integrated PV products in order to validate Lightyear's technology and design . These vehicles will help to demonstrate added value through energy yield and real-world data and input for designing for safety, mechanical durability, vibration impact and waterproofness.

In November 2019, IM Efficiency, a Dutch company focused on integrating solar on truck trailers, installed the first trucks in the Netherlands with the SolarOnTop technology and subsequently in other countries as well. These panels will serve to reduce fuel consumption and CO_2 emissions.

In Germany, Vehicle Integrated Photovoltaics is a recent research topic for automotive companies (e.g. Audi, Continental, a2-solar), Start-Ups (Sono Motors) and public funded research institutes (e.g. Jülich, ISFH, F-ISE, HZB). The German Federal Ministry for Economic Affairs and Energy is currently funding two large research projects on the application of VIPV in Truck trailers ("Lade-PV") and light commercial vehicles ("Street"). The objective of the "Street" project is to demonstrate the economic and ecological viability of VIPV in electrically driven delivery cars. In a demonstration car "WORK L" of the company StreetScooter, high-efficient PV modules (based on Si heterojunction cells from Meyer-Burger) with a total power 2,400 W are installed. The converted PV energy will be used for driving and should cover a fraction of at least 30% (latitude Germany) of the energy demand on annual average.

With 111,6 GW of global installations in 2019, the PV market is still leading the renewable energy transition in terms of added capacity. The cumulative capacity reached 623,2 GW at the end of 2019, representing a PV penetration of 3,3%. Despite the very impressive track record of PV installation rates in the last years, these figures are still largely insufficient with regards to the Paris Climate Agreement. The cost reduction evolution of PV technology enabled a larger and more sustainable market uptake. Nonetheless, national integrated energy and climate plans and international collaboration are required to accelerate the energy transition and to reach less accessible markets segments for instance.

Overall, the main PV development trend observed in 2019 was similar to 2018 and even more pronounced: a Chinese market slowdown (a 14,0 GW market decrease compared to 8,6 GW market decrease in 2018) which was again counterbalanced by the (re)emergence of several markets. This uninterrupted market growth of the global PV market year after year is encouraging investments in both upstream manufacturing and downstream installation segments.

The acceleration of the PV roll-out is even more crucial considering the electrification of the transport and the heating and cooling sector. The coupling of local renewable electricity production to both domestic and industrial energy demand is key to decarbonize the other sectors traditionally relying on fossil fuels consumption. Consequently, PV production should increase even faster to meet the increasing demand for electricity.

The market dynamics were very diverse in Europe: several European markets reconnected with growth after several years of market stagnation (Austria, Belgium, Germany, Italy, Portugal, Spain), others stayed stable (Denmark, France, Switzerland) or steadily increased (the Netherlands, Norway, Sweden) while other markets started their development more recently (Poland, Russia, Ukraine). In the Asia-Pacific region, Vietnam is the main newcomer next to established markets (Australia, India, Japan, Korea and Malaysia). In the Americas, growth was driven by the same major markets as in previous years (Brazil, Mexico, United States). In Africa, most of the new capacity was installed in Egypt and to a lesser degree in South Africa, while in the Middle East the main markets in 2019 were the UAE, Israel and Jordan.

Recently, the most competitive tenders are below 14 USD per MWh and further important cost reductions are still expected until 2030. While these extremely competitive prices are not representative of the average PV installations, the overall PV competitiveness is still expanding, hence paving the way to new market segments without any form of financial incentive.

The cumulative PV capacity installed at the end of 2019 allows to avoid 700 Mt of CO_2 eq emissions yearly. This contributed to the flattening of the global CO_2 emissions after two successive years of increase. The global CO_2 emissions are expected to decrease in 2020, due to the impact of the sanitary measures for the COVID-19 pandemic. However, this reduction is not likely to last if the economic activities return to their normal pace. As mentioned above, a broader decarbonization of the energy sector and of the economy is needed to achieve rapid and sustainable CO_2 emission reductions.

CONCLUSION / CONTINUED

The impact of the COVID-19 pandemic is expected to be rather limited on the PV market growth in 2020 and in the following years. Indeed, while some countries experienced reduced installations due to lockdown measures, other markets experienced larger uptakes in the residential markets and many countries reaffirmed their support for renewable technologies in their recovery plans to limit the economic and social impact of the pandemic. PV development is increasingly being driven by the natural competitiveness of PV in several segments and the further cost decrease of storage is going to reinforce this trend. While, the future of the PV sector is bright given the technological and price developments, the nations, and the industry's efforts must increase and converge to ensure the younger generation's future.

ANNEXES

ANNEX 1: AVERAGE 2019 EXCHANGE RATES

COUNTRY	CURRENCY CODE	EXCHANGE RATE (1 USD =)
AUSTRALIA	AUD	1,439
CANADA	CAD	1,327
CHILE	CLP	787,761
CHINA	CNY	6,910
DENMARK	DKK	6,67
EUROZONE	EUR	0,893
ISRAEL	ILS	3,563
JAPAN	JPY	109,008
KOREA	KRW	1165,697
MALAYSIA	MYR	4,19
MEXICO	MXN	19,246
MOROCCO	MAD	9,614
NORWAY	NOK	8,802
SOUTH AFRICA	ZAR	14,448
SWEDEN	SEK	9,457
SWITZERLAND	CHF	0,994
THAILAND	THB	31,032
TURKEY	TRY	5,685
UNITED STATES	USD	1

SOURCE IRS.

ANNEXES / CONTINUED

ANNEX 2: CUMULATIVE INSTALLED PV CAPACITY (MW) FROM 1992 TO 2019

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
AUSTRALIA	7	9	11	13	16	18	21	23	26	30	35	41	47	55	64	74	104	189	578	1 444	2 491	3 283	4 131	5 057	5 908	7 178	11 586	16 344
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
BELGIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	22	108	651	1 070	2 116	2 829	3 079	3 201	3 322	3 527	3 849	4 274	4 861
CANADA	1	1	2	2	3	3	4	6	7	9	10	12	14	17	20	26	33	95	282	559	766	1 211	1 843	2 519	2 665	2 933	3 095	3 326
CHILE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	12	223	590	1 145	1 774	2 406	2 694
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	205 242
DENMARK	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	3	3	4	7	29	499	699	752	980	1 061	1 138	1 254	1 362
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
FRANCE	2	2	2	3	4	6	8	9	11	14	17	21	24	26	38	76	180	371	1 209	2 973	4 093	4 747	5 701	6 605	7 201	80 99	8 968	9 934
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
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	1 914
ITALY	8	12	14	16	16	17	18	18	19	20	22	26	31	37	50	100	496	1 277	3 605	13 141	16 796	18 198	18 607	18 915	19 297	19 682	20 108	20 865
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
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	11 229
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
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
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
NETHERLANDS	0	0	0	0	0	1	1	1	5	9	16	22	40	43	45	49	59	69	90	149	287	650	1 007	1 526	2 135	2 901	4 522	6 874
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	67	120
PORTUGAL	0	0	0	0	0	0	0	0	0	0	0	2	2	2	4	15	62	110	134	175	244	299	416	454	520	584	672	827
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	2 560
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	48 97	5 159	9 910
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
SWITZERLAND	5	6	7	7	8	10	11	13	15	18	19	21	23	27	30	36	48	74	111	211	437	756	1 061	1 394	1 664	1 906	2 173	2 498
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
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	7 149	8 547
USA	0	0	0	0	0	0	0	0	0	0	0	0	111	190	295	455	753	1 188	2 017	3 937	7 130	12 076	18 321	25 821	40 973	51 818	62 498	75 770
TOTAL IEA PVPS	50	65	90	114	149	204	269	369	568	777	1 135	1 547	2 665	4 077	5 482	7 834	14 059	21 594	36 269	64 712	89 694	121 682	156 583	198 001	264 872	348 379	432 008	509 872
TOTAL NON IEA PVPS	0	0	0	0	0	0	0	0	1	8	15	35	55	68	101	135	245	825	3006	5 709	10 312	15 863	20 985	29 926	39 756	58 904	79 642	113 362
TOTAL	**50**	**65**	**90**	**114**	**149**	**204**	**269**	**369**	**569**	**785**	**1 150**	**1 582**	**2 721**	**4 146**	**5 583**	**7 969**	**14 304**	**22 419**	**39 274**	**70 421**	**100 006**	**137 545**	**177 568**	**227 928**	**304 627**	**407 283**	**511 650**	**623 234**

SOURCE IEA PVPS 8 OTHERS.

ANNEX 3: ANNUAL INSTALLED PV CAPACITY (MW) FROM 1992 TO 2019

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
AUSTRALIA	7	2	2	2	3	3	3	2	3	4	5	6	6	8	9	11	30	85	389	866	1 047	792	848	926	851	1 270	4 408	4 758
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
BELGIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	19	86	543	419	1 046	713	250	122	121	205	322	425	587
CANADA	1	0	0	0	1	1	1	1	1	2	1	2	2	3	4	5	7	62	187	277	207	445	633	675	146	268	162	232
CHILE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	210	367	555	629	632	288
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	30 100
DENMARK	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	3	23	470	199	53	228	82	77	116	109
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
FRANCE	2	0	0	1	2	2	2	2	2	3	3	4	3	2	12	38	104	191	838	1 764	1 120	654	954	903	596	898	869	966
GERMANY	6	3	3	6	10	14	12	16	44	62	120	139	670	951	843	1 271	1 950	4 446	7 440	7 910	8 161	2 633	1 190	1 324	1 455	1 614	2 888	3 835
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	556
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	383	385	426	758
JAPAN	19	5	7	12	16	32	42	75	122	123	184	223	272	290	287	210	225	483	991	1 296	1 718	6 968	9 740	10 811	7 889	7 460	6 662	7 031
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	3 130
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
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
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
NETHERLANDS	0	0	0	0	0	0	0	0	4	3	8	6	18	4	2	3	10	10	21	59	138	363	357	519	609	766	1 621	2 352
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	23	51
PORTUGAL	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	11	47	48	24	41	69	55	117	38	66	64	88	155
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	151
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	4 751
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
SWITZERLAND	5	1	1	1	1	1	2	2	2	2	2	2	2	4	3	7	12	26	37	100	226	319	305	333	270	242	267	325
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
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	2943	1 398
USA	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	13 272
TOTAL IEA PVPS	50	15	25	24	34	55	64	101	199	209	358	412	1 118	1 422	1 405	2 352	6 225	7 536	14 674	28 443	24 986	31 987	34 901	41 418	66 870	83 507	83 629	77 865
TOTAL NON IEA PVPS	0	0	0	0	0	0	0	0	1	7	7	20	21	13	33	34	110	580	2 181	2 703	4 601	5 551	5 122	8 941	9 829	19 146	20 738	33 720
TOTAL	50	15	25	24	34	55	64	101	200	216	365	432	1 139	1 435	1 437	2 386	6 335	8 116	16 855	31 147	29 587	37 538	40 023	50 359	76 700	102 653	104 367	111 585

SOURCE IEA PVPS 8 OTHERS.

LIST OF FIGURES & TABLES

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ISBN 978-3-907281-01-7
9 783907 281017 >