INTERNATIONAL SOLAR ALLIANCE

WORLD SOLAR MARKET REPORT

Foreword

Dr. Ajay Mathur
Director General
International Solar Alliance

As the world moves away from fossil fuel-based energy generation, renewable energy has grown in importance. Within renewables, solar energy has stood out as the stellar performer, seeing a meteoric rise in little over a decade. Solar's share in power sector generation has grown from 0.1% in 2010 to 3.7% in 2021. It is now the fastest-growing energy generation sourceand accounts for a significant share of new renewable generation capacity.

The market for solar technologies is thriving and set to continue its growth trajectory. This market growth for solar has been driven by the growth of solar photovoltaics, and the global photovoltaic capacity has reached TW scale through design, not merely by chance. Falling costs, increasing technology options, and supportive government programmes and policies have engineered this growth. Additionally, the flexibility and modularity of solar technologies have allowed them to be deployed in various applications and sectors.

The deployment of off-grid solar and solar thermal also helps the technology meet demands that other renewable technologies cannot. A variety of long term and short term scenarios for the future of solar capacities have been prepared by leading analysts. While anticipating markets accurately is difficult, studying these scenarios makes one thing clear: solar is set to grow.

Annual capacity addition requirements range from hundreds of GW to TW scale, and the solar fleet may be tens of times larger in just a few decades. While the growth figures for solar markets are certainly promising, several key barriers continue to hamper growth. Challenges such as the availability of workers, grid integration constraints, social acceptance of omnipresent solar deployment, and continued support to the fossil fuel industry hamper the ability to deploy large scale solar capacity. Solar capacities also need to see growth across all regions. Addressing these challenges will go a long way to smoothen the growth trajectory for solar. Through this flagship annual World Solar Market Report, ISA aims to illustrate the development of markets across the world for different solar technologies, highlight the markets for various solar applications, study the different future PV scenario projections available, and provide a qualitative overview of the main policies and instruments used to support solar around the globe.

I congratulate the ISA team and all the stakeholders involved in the production of this Report for their contribution and support. I look forward to sharing the ISA World Solar Market Report with the global solar community.

Abbreviations

AC	Alternating Current
AEM	Anion Exchange Membrane
AFD	Agence Française de Développement
AfDB	African Development Bank
AI	Artificial Intelligence
AIM	American Innovation and Manufacturing
ALD	Atomic Layer Deposition
APAC	Asia Pacific
APV	Agri- PV
ASEAN	Association of Southeast Asian Nations
BCD	Basic Custom Duty
BESS	Battery Energy Storage System
BIPV	Building Integrated Photovoltaics
BMZ	Federal Ministry of Economic Cooperation and Development
BNEF	Bloomberg New Energy Finance
BoM	Bill of Materials
BoS	Balance of System
BSF	Back Surface Field
BTM	Behind the Meter
CAES	Compressed Air Energy Storage
CAISO	California Independent System Operator
CEEW	Centre for Energy, Environment, and Water
CIGS	Copper Indium Gallium Selenide
CIS	Copper Indium Selenide
CPSU	Central Public Sector Undertaking
CSP	Concentrated Solar Power
CTM	Cell to Module
CUF	Capacity Utilisation Factor
CVD	Chemical Vapor Deposition
CZ	Czochralski
DAT	Dual Axis Trackers
DC	Direct Current
DCR	Domestic Content Requirement
DS	Directional Solidification
DW	Diamond Wire
EIB	European Investment Bank
EIM	Energy Imbalance Market
EPC	Engineering, Procurement, and Construction
EPR	Extended Producer Responsibility
ESS	Energy Storage System
EV	Electric Vehicle
EVA	Ethyl Vinyl Acetate
EXIM	Export-Import Bank of the United States
FBR	Fluidized Bed Reactor
FPV	Floating Solar PV
FY	Financial Year
FZ	Float Zone
GDP	Gross Domestic Product
GH	Green Hydrogen
GHG	Greenhouse Gas
GTAM	Green Term Ahead Market
GW	Gigawatt
HDH	Humidification Dehumidification
HJT	Heterojunction
HSAT	Horizontal Single Axis Trackers
IBC	Interdigitated Back Contact
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ILO	International Labour Organisation
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISA	International Solar Alliance
ITRPV	International Technology Roadmap for Photovoltaic
KIUC	Kaua'I Island Utility Cooperative
KSEB	Kerala State Electricity Board
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
LID	Light Induced Degradation
MBB	Multi Busbar
MEB	Multiple Effect Boiling
MED	Multiple Effect Distillation
MEH	Multiple Effect Humidification
MGS	Metallurgical Grade Silicon
MSF	Multi Stage Flash Distillation
M-SIPS	Modified Special Incentive Package Scheme
MSP	Minimum Sustainable Price
MT	Metric Ton
MW	Megawatt
NDC	Nationally Determined Contributions
NGO	Non-Governmental Organisation
NREL	National Renewable Energy Laboratory
NTPC	National Thermal Power Corporation
PECVD	Plasma Enhanced Chemical Vapor Deposition
PEM	Polymer Electrolyte Membrane
PERC	Passivated Emitter and Rear Cell
PERL	Passivated Emitter with Rear Locally Diffused
PERT	Passivated Emitter, Rear Totally Diffused
PET	Polyester
PID	Potential Induced Degradation
PLI	Production Linked Incentive
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan
POE	Polyolefin Elastomers
PSG	Phosphosilicate Glass
PV	Photovoltaic
PVDF	Polyvinylidene Fluoride
PVF	Polyvinyl Fluoride
PVPS	Photovoltaic Power Systems Programme
RCRA	Resource Conservation and Recovery Act
RE	Renewable Energy
RO	Reverse Osmosis
RTC	Round The Clock
SCADA	Supervisory Control and Data Acquisition
SHJ	Silicon Heterojunction
SMES	Superconducting Magnetic Energy Storage
SOEC	Solid Oxide Electrolysers
SRV	Surface Recombinant Velocity
SSEF	Shakti Sustainable Energy Foundation
SWCT	Smart Wire Connection Technology
TCO	Transparent Conducting Oxides
TCS	Trichlorosilane
TOPCon	Tunnel Oxide Passivated Contact
TR	Tiling Ribbon
TW	Terawatt
UAE	United Arab Emirates
UHV	Ultra High Voltage
UK	United Kingdom
UMG	Upgraded Metallurgical Silicon
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VIPV	Vehicle Integrated PV
VPP	Virtual Power Plants
VRE	Variable Renewable Energy
WB	World Bank
WEEE	Waste Electrical and Electronic Equipment

Table of Contents

Executive Summary

The urgency to reduce global emissions has never been as high as today. The 2021 Intergovernmental Panel on Climate Change (IPCC) warned that the global greenhouse gas emission (GHG) in 2019 were 12% higher than in 2010 and 54% higher than in 2019. The panel also highlighted that the average global temperature is expected to reach or exceed 1.5°C warming by 2040. The consequences are increasingly visible with more frequent heat waves, floods, forest fires and others natural disasters with drastic impacts on populations.

The largest contributing sectors for the increase of emissions are electricity and heat production, transportation, manufacturing, industry, agriculture, and buildings. With a share of 31% of global emissions, the electricity and heat generation's roles cannot be underestimated. Their emissions are mainly resulting from the burning of fossil fuels such as coal and gas which need to be replaced by cleaner source of energy. Therefore, as part of the available solutions, renewable power technologies will play a key part in the transition toward a net-zero emission economy.

The unit cost of the low-emission technologies has fallen continuously since 2010 thanks to innovations and policy packages that have enable their deployment. Within the range of renewables, solar photovoltaics' (PV) cost has experienced a 90% reduction in the last 10 years, which has allowed for exponential growth and a global cumulative capacity reaching 920 GW in 2021. Driven by a technological and financial maturity, solar PV is now a leading actor in the decarbonisation plan of most countries. As a result, prospects look bright for the technology as growth is expected to continue in the coming years and decades.

In light of the center role of the solar sector, this Solar Market Report illustrates the development of markets across the world for different solar technologies. It

During the period 2019-2021, solar energy expansion outpaced any other technology, with a compound annual growth rate of 21%. 2021 was also the first year when solar and wind together met more than 10% of the world's global power demand. Solar represents 3.7% of all generated electricity in 2021 and wind represents 6.6%.

analyses the deployment of solar PV, whether on- or off- grid, rooftop or ground-mounted, as well as more specific application such as Building Integrated PV, agri-voltaics and floating PV. The report's scope also includes solar thermal electricity and solar thermal heating.

Assessing the role of solar in the global energy and electricity landscape, the report highlights that solar's share in total energy consumption reached 1.6% in 2021, while the total share of renewables was at 13.5% in the same year. Although solar's share remains small, solar energy is the fastest growing source of energy from the past 17 years. During the period 2019-2021, solar energy expansion outpaced any other technology, with a compound annual growth rate of 21%. 2021 was also the first year when solar and wind together met more than 10% of the world's global power demand. Solar represents 3.7% of all generated electricity in 2021 and wind represents 6.6%.

The study analyses the historical deployment of solar technologies across the world. In 2021, the world reached 920 GW of on-grid solar PV, 9 GW of off-grid solar PV, 522 GWth of solar thermal power and 6.4 GW of concentrated solar power (CSP). The last decade saw a surge in solar growth, with the global solar PV market increasing by 445%, raising from 30 GW in 2011 to 163 GW in 2021. Initially driven by European installations, since 2012 the market has been led by the Asia-Pacific region, which accounted for 57% of annual additions in 2021, and 59% of the global PV fleet. The analysis also highlights that, on average, 119 watts of solar PV are installed per every individual in the world, a 20 points increase from 2020. Large discrepancies between countries are also identified: while Australia has been the first country to reach the 1 kW per capita mark in 2021, several nations across the global are still lagging behind.

The report provides an overview of different future PV capacity scenarios from intergovernmental organisations, research institutes and other stakeholders. From the 163 GW annually installed in 2021, the world's solar market is expected, on average, to grow 71% to 278 GW by 2025. In the medium and long term, the comparison emphasizes the difference in solar PV forecasts. By 2030, global solar PV capacity ranges between 4.9 TW to 10.2 TW across the scenarios. CSP technology is also poised to experience notable growth, increasing 11 to 74 times to 73-474 GW by 2030 from the 6.4 GW in 2021 depending on the scenario. The 2050 evaluation depicts even stronger differences in solar deployment level, with PV capacities standing between 12.7 TW and 63.4 TW, equivalent to 14 to 69 fold growth from 2021.

A qualitative overview of the main policies and instruments that are used across the globe to support the development of solar energy is also provided, together with an analysis of the main challenges and barriers that are typically standing on the road of solar development.

By 2030, global solar PV capacity ranges between 4.9 TW to 10.2 TW across the scenarios. CSP technology is also poised to experience notable growth, increasing 11 to 74 times to 73-474 GW by 2030 from the 6.4 GW in 2021 depending on the scenario.

Approach & Methodology of the Report

The urgency to reduce global emissions has never been as high as today. The 2021 Intergovernmental Panel on Climate Change (IPCC) warned that the global greenhouse gas emission (GHG) in 2019 were 12% higher than in 2010 and 54% higher than in 2019. The panel also highlighted that the average global temperature is expected to reach or exceed 1.5°C warming by 2040. The consequences are increasingly visible with more frequent heat waves, floods, forest fires and others natural disasters with drastic impacts on populations.

1.1 Methodology

The data on solar energy included in this report comes from a variety of available sources, which at times present significant differences. Provided that an accurate assessment of deployed solar capacities across the world's countries and regions is a challenging task, analysts and intergovernmental organisations use different methodologies and sources to calculate the evolution of solar worldwide. For historical data, it has been chosen to calculate the simple average of available major sources. This is the case for all the figures displaying historical data that reference multiple sources. By contrast, forecast scenarios are described at the individual organisation level with the aim to capture the different level of ambition of each scenario. Data on segmentation and off-grid solar also present methodological inconsistencies. This is because the exact division between residential, commercial & industrial, and utility-scale solar changes according to the sources, while some sources report on- and off-grid solar as a single category. Whenever possible, data have been adjusted to allow for comparison.

Data used in this report is provided to the best knowledge of the authors, based on information publicly available and through bilateral exchanges with the sources.

Global Energy Transformation

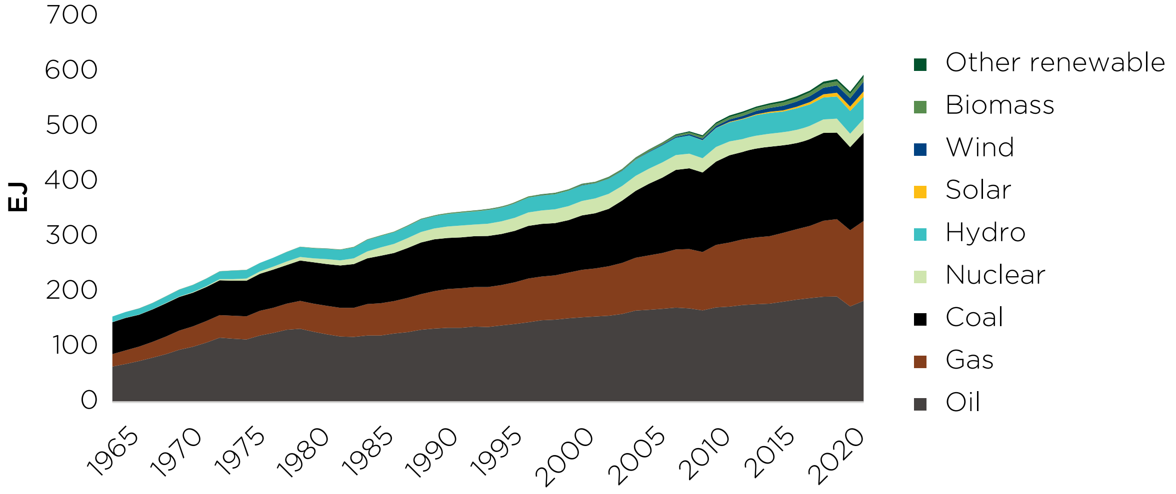
Over the 2019-2021 period, the CAGR of solar power was 21% - the highest among all energy sources. Wind power is second, with a 14% CAGR while biomass ranks 3rd with 6% CAGR. Overall, global energy consumption increased by 1% in the same timeframe.

2.1. Pathway for Global Energy Transformation

In the last decades, the world has witnessed a more and more rapid shift in the energy paradigm. The increase in global energy demand is a long-term trend that only in recent years has been accompanied by a progressive growth in the use of renewable energy sources. From 1965 to 2021, global primary energy consumption has increased fourfold (Fig. 1).

From 2019-2021, the CAGR of solar power was 21% - the highest among all energy sources. Wind power is second with a 14% CAGR, while biomass ranks 3rd with 6% CAGR. Overall, global energy consumption increased by 1% in the same period.

Fig. 1 Global primary energy consumption by source, 1965-2021

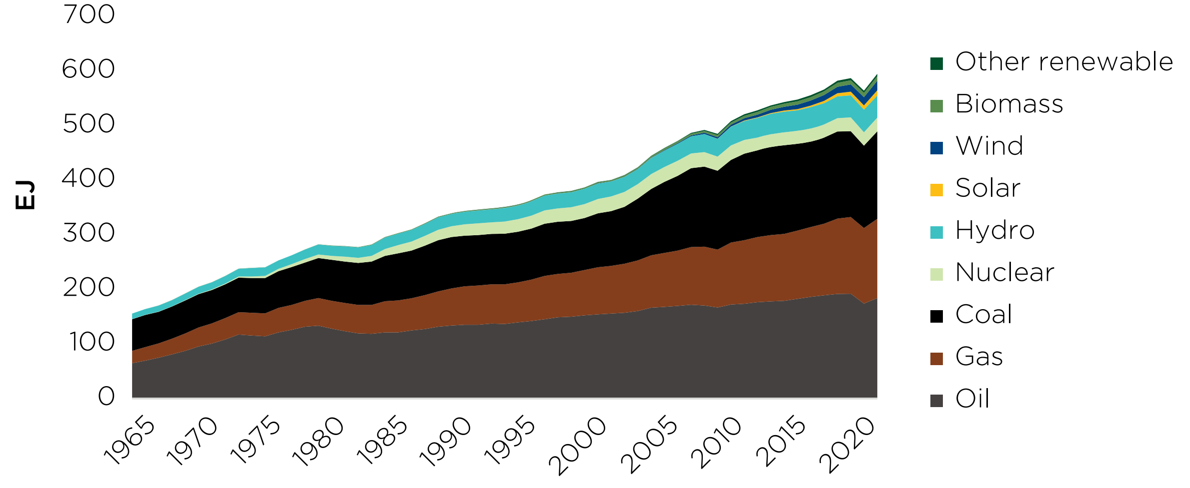


Source: BP

The share of renewable energy in total primary energy consumption has slowly increased from 6.5% to 13.5% between 1965 and 2021.

Throughout this period, the share of renewable energy in total energy consumption has slowly increased from 6.5% to 13.5%. When looking in closer detail at the renewable energy technologies, it can be observed that the share of hydro, which constituted nearly all the renewable capacity in the early decades, has remained basically the same – ranging around 6-7%. The growth in renewable energy is due to non-hydro technologies. Non-hydro RES, which were virtually inexistent in the 1960s and still below 1% at the turn of the century, have grown to 6.7% of total energy consumption by 2021 (Fig. 2). In the meantime, the shares of conventional energies have changed, but their ranking across technologies remains the same. Oil, the biggest energy provider in 1965 with a 41.5% share, is still the largest contributor with a 31% share, while coal retains the second rank, though its share has also decreased from 37.3% to 26.9%. Conversely, gas has grown its share from 14.6% in 1965 to 24.4% in 2021, but still maintained its third position. The overall share of fossil fuels in total primary energy consumption has decreased 11.1% points from 93.4% in 1965 to 82.3% in 2021, due to the increase in RES and nuclear, the latter standing at 4.3% in 2021, a 2.4% points decline from its maximum in 2001.

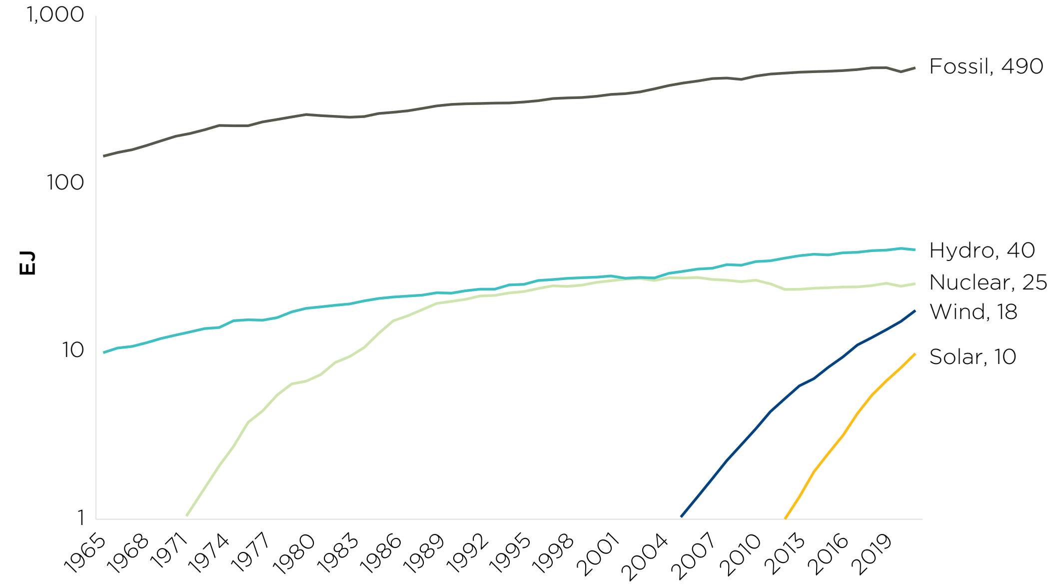
Fig 2. Share of global primary energy consumption by source, 1965-2021



Source: BP

Looking at the pace of energy technology uptake since 1965, it is important to acknowledge the disruptive effect of wind and solar technologies in the last two decades. Figure 3 displays the contribution of different technologies to global primary energy demand using a logarithmic scale. It can be observed that fossil and hydro technologies show a more even growth path than wind and solar, which both maintain a very steep pace of deployment and solar power keeping the lead. Nuclear energy, by contrast, grew very fast in the 1970s and 1980s, but its market development has stagnated since then.

Fig 3. Global primary energy consumption by source, 1965-2021

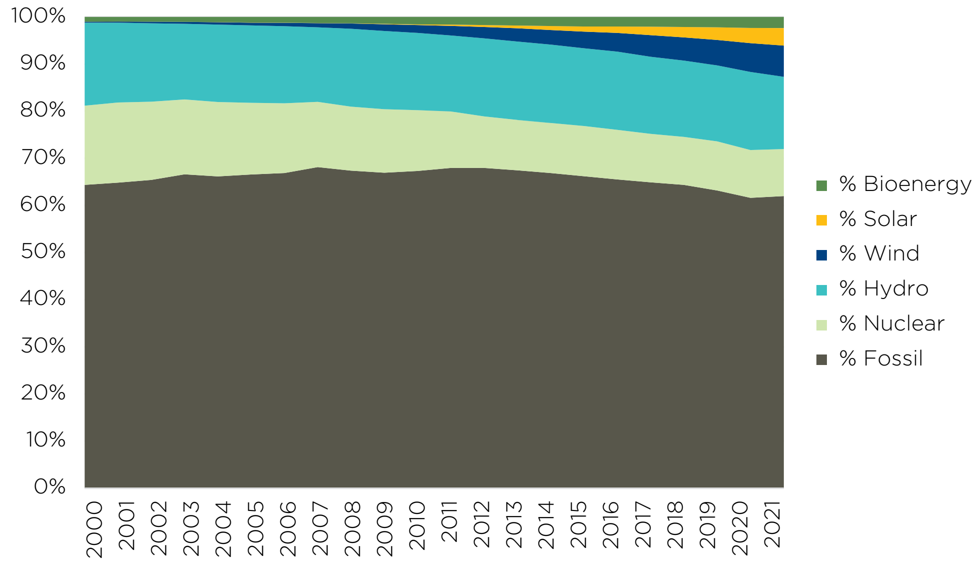


Source: BP
Note: the vertical axis uses a logarithmic scale.

When focusing on the development of global electricity generation over the last 20 years, the growth of non-hydro renewable energy sources is displayed much more prominent (Fig. 4). While the wind, solar and biomass grew with a 16% annual growth rate from a combined 1.2% share to 12.7% in 2021, non-renewable energy sources showed negative growth rates, decreasing its share from 81% to 71.7%. Although traditional generation sources maintained the lion's share of global electricity generation in 2021, this was the first year, flexible renewable technologies wind and solar together provided more than 10% of global electricity demand. The strong growth trend for solar and wind will not stop anytime soon, and it is set to become even more pronounced as countries around the world look at cost-competitive and secure power solutions for their energy and climate protection needs.

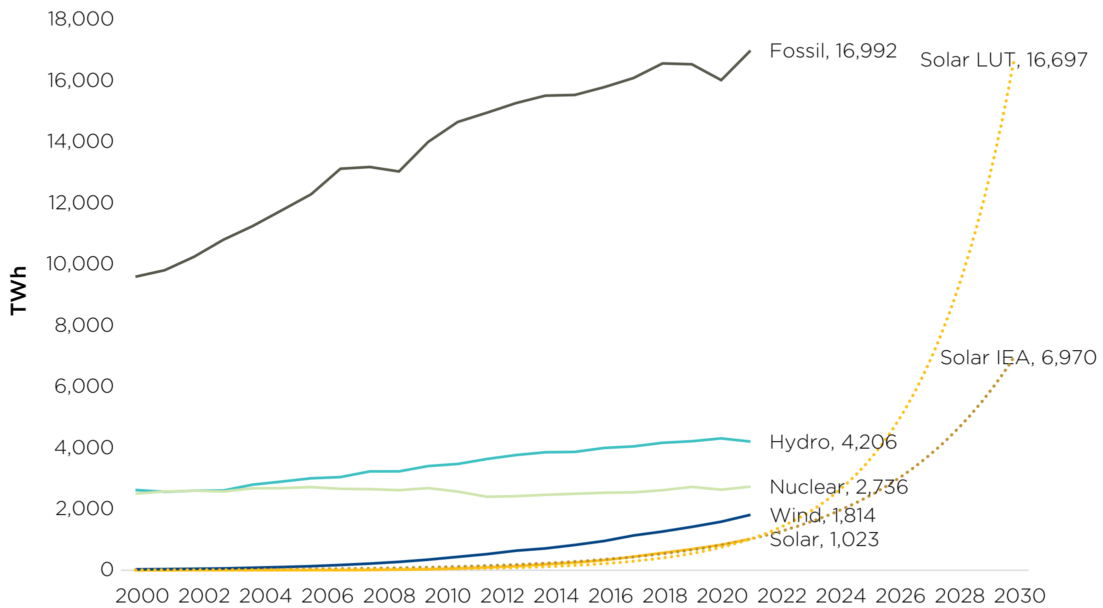
Solar and wind produced more than 10% of global electricity for the first time in 2021. From generating 2.6% of all electricity in 2019, solar PV increased to 3.7% in 2021.

Fig 4. Share of global electricity generation by source, 2000-2021



Source: Ember (2022)

Fig 5. Global electricity generation by source, 2000-2021



Source: Ember, LUT, IEA net zero, ITRPV

2.2. Global Energy Transformation: The Role of Solar

Until recently, solar did not play any role in global total energy production. In 2010, solar's contribution to global energy demand reached a mere 0.1%. Today, solar energy still constitutes only 1.6% of global energy generation. But when it comes to the power sector alone, solar's share has grown more rapidly, from a share of 0.1% in 2010 to 3.7% in 2021. While this contribution may still appear small, these developments need to be looked at from the right perspective. Solar's total share in 2021 increased by 0.5% absolute compared to the year before, making the technology again the fastest power growing generation source. Of the more than 300 GW of new renewable power generation capacity installed in 2021, more than half was provided by solar PV alone. In the long term, half of the total generation capacity is expected to come from solar PV. More information on this can be found in the ISA Technology Report.

Global Solar Market Overview

3.1. Evolution of the solar market

Cumulative solar installation end of 2021:
***On-grid solar PV: 920 GW**
***Off-grid solar PV: 9 GW**
***Solar thermal: 522 GWth**
***Concentrated Solar Power: 6.4 GW**

Solar technologies have undergone exponential growth in the last two decades (fig 6 & 7).

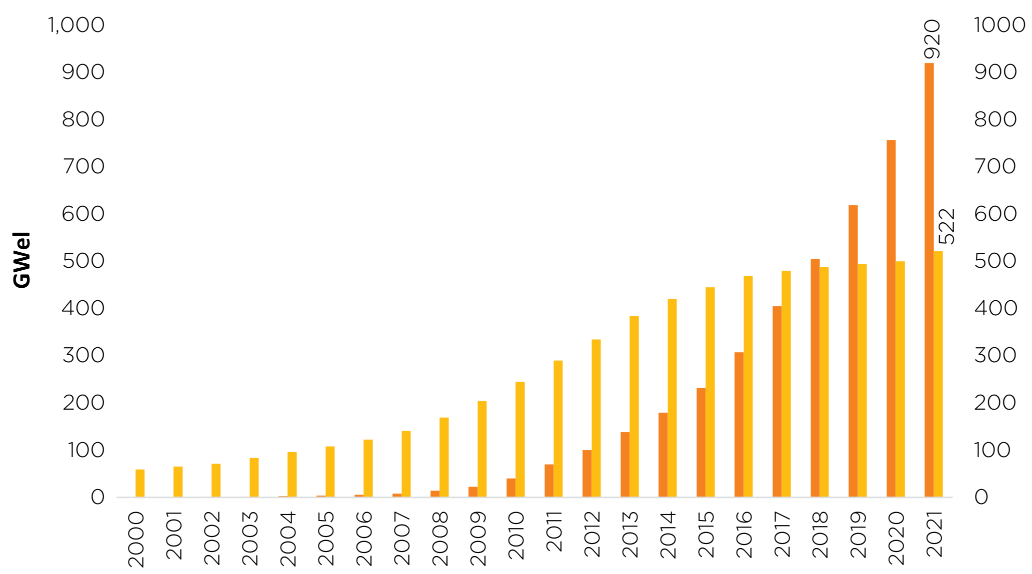
Solar photovoltaics, the most diffused technology today, is the main contributor to such rapid growth. At the turn of the 21st century, only around 1600 megawatts (MW) of PV capacity were installed across the globe. With the introduction of the first feed-in tariff support programmes in Germany and Japan, solar PV started expanding rapidly in the distributed rooftop segment, at first, primarily for residential applications. Thanks to a rapid decrease in cost, its superior technological versatility, and backed by incentive programmes in several geographies, the market for large-scale solar PV power plants started to evolve a few years later. By 2008, total installed PV capacity had passed the 10 gigawatts (GW) mark; by 2013, it passed 100 GW; only five years later, by 2018, it exceeded 500 GW; and in the spring of 2022, it had reached the terawatt (TW) scale.

Today, the vast majority of installed solar PV capacity is connected to the grid, but traditionally PV technology had been developed for powering devices in remote areas and had later evolved into a key tool for rural electrification. At around 9 GW of cumulative capacity, **off-grid PV** installations – from small solar home systems to solar mini grids – constitute less than 1% of total PV capacity. As still over 700 million people miss access to stable electric supply, off-grid PV remains a large market with nearly 500 million users worldwide in 2021. Besides photovoltaics, the other main solar technology used is **solar thermal energy**. Making use of the sun' thermal energy, solar thermal technologies can be employed for heating and cooling purposes in residential, commercial and industrial sectors (solar thermal heat). The solar thermal industry had already installed 245 GWth by 2010, but grew much slower than PV over the last decade, reaching 522 GWth at the end of 2021.

The solar thermal industry had already installed 245 GWth by 2010, but grew much slower than PV over the last decade, reaching 522 GWth at the end of 2021.

Solar thermal energy can also be used to produce electricity through **concentrated solar power (CSP)**, although this technology is much less deployed than the other two. In the early days considered a very attractive way to harnessing solar for power generation, CSP has not fulfilled the promises, only increasing total installed global capacities from 0.4 GW in 2000, to 1.3 GW in 2010, and 6.4 GW by 2021 – that's less than total installed off-grid solar capacities (see Fig. 6).

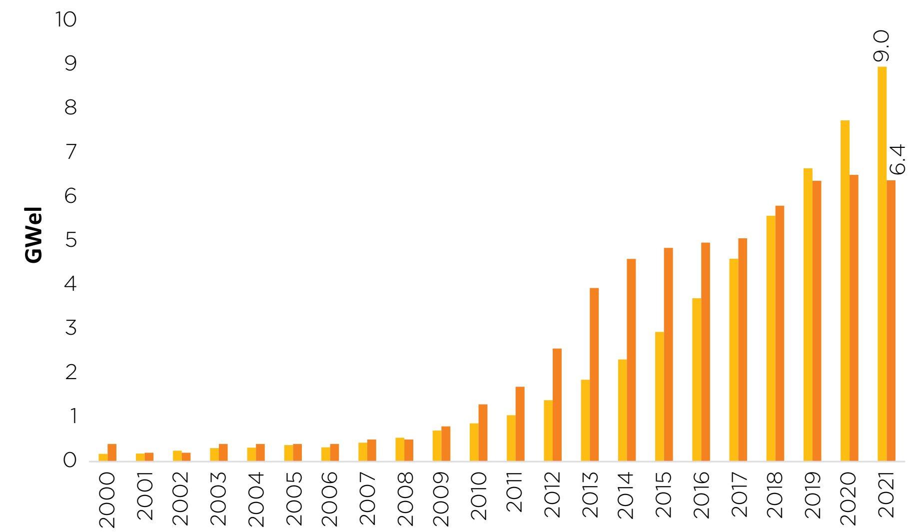
Fig 6. Cumulative on-grid solar PV and solar thermal capacity, 2000-2021



Source: BNEF, IEA, IEA-SHC, IHS, IRENA, SPE

In the early days considered a very attractive way to harnessing solar for power generation, CSP has not fulfilled the promises, only increasing total installed global capacities from 0.4 GW in 2000, to 1.3 GW in 2010, and 6.4 GW by 2021

Fig 7. Cumulative off-grid solar PV and CSP capacity, 2000-2021



Source: IEA, IHS, IRENA, REN21

BOX:1
Market Reporting – AC or DC?

On-grid PV systems use inverters to convert electricity for direct current (DC) to alternating current (AC), in order to provide electricity that can be fed into the grid. Typical PV modules are therefore coupled with inverters of different sizes, which integrated with other subcomponents, compose a PV system. However, certain types of PV modules, called AC modules, are equipped with integrated inverters that enables their direct connection to the grid.

The conversion factor between DC and AC nameplate module capacity differs across world regions, due to the different approaches that are typically chosen to set up the PV system. Observed conversion factors usually range between 1.1 and 1.25 DC values per AC unit in most cases.

When reporting installed PV capacity, countries and organisations usually refer to DC values. This standard approach helps understand the amount of deployed PV technology from the supplier perspective, or, in other words, from the point of view of the module technology produced, sold and installed. By contrast, certain organisations that look at PV energy as one of the energy generation sources among different technologies and rather focus their attention to other aspects like impacts on the grid tend to use AC values. In addition to this complexity, in a number of countries it is usual to report PV values in AC numbers. This is the case, among others, for India, Japan and Spain, to name a few.

In this report, all numbers are expressed in DC values. Sources reporting in AC values have been converted into DC values, using ratios that are most appropriate to the country or region's characteristics.

3.2. Solar PV Installations

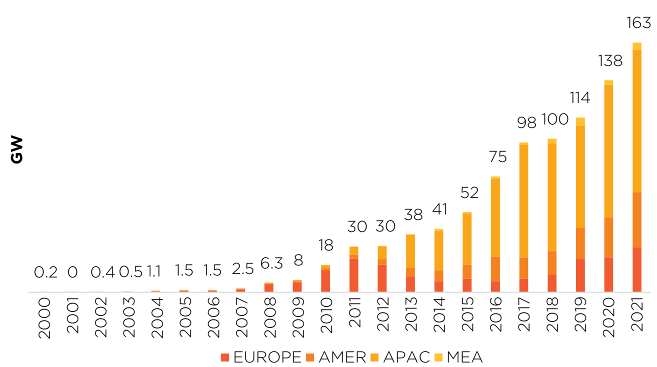
3.2.1. Annual and cumulative deployment

Solar PV technology started gaining traction in the early 2000s, when the first support programmes for residential PV systems were introduced in a few pioneering countries. Fast forwarding to 20 years later, the landscape for solar PV has dramatically changed. Today, solar PV systems are being deployed in almost every country around the world, and this technology is widely recognized to be a pillar of the renewable energy transition. World on-grid annual PV installations reached the GW mark in 2004, passed 10 GW in 2010, 100 GW in 2018 and stood at 163 GW in 2021. With a 37% compound annual growth rate (CAGR), solar PV emerged as the fastest growing energy technology and the one with the brightest prospects.

The market size in 2021 represents a 18% increase from 2020 and a 445% growth compared to 10 years earlier (see Figure 8).

The Solar PV Market grew 445% over the last 10 years

Fig 8. Annual global solar PV deployment, 2000-2021

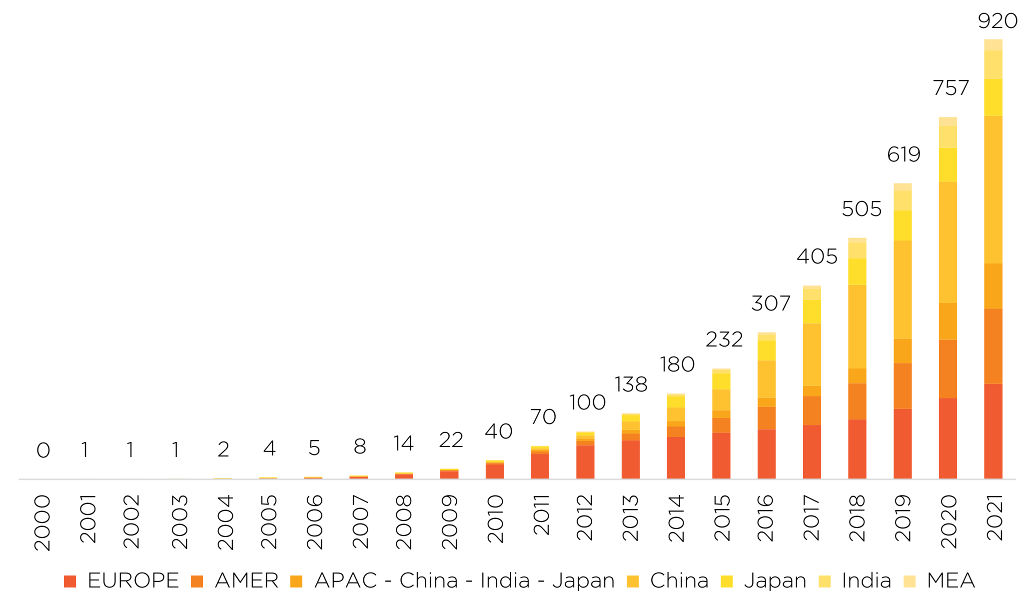


Source: BNEF, IEA, IHS, IRENA, SPE

The story is very similar when we turn to cumulative solar PV capacity (see Figure 9). Since the world grid-connected its first ever solar panel this capacity accumulated to 920 GW by the end of 2021. This is up 21% from the 757 GW a year earlier, by 2020. Retrospectively, the total fleet of solar PV increased almost 600 times from the year 2000 and experienced 1,200% growth over the total capacity installed by 2011, when 70 GW of solar PV was deployed.

920 GW of solar PV was installed by the end of 2021.

Fig 9. Cumulative global solar PV deployment, 2000-2021



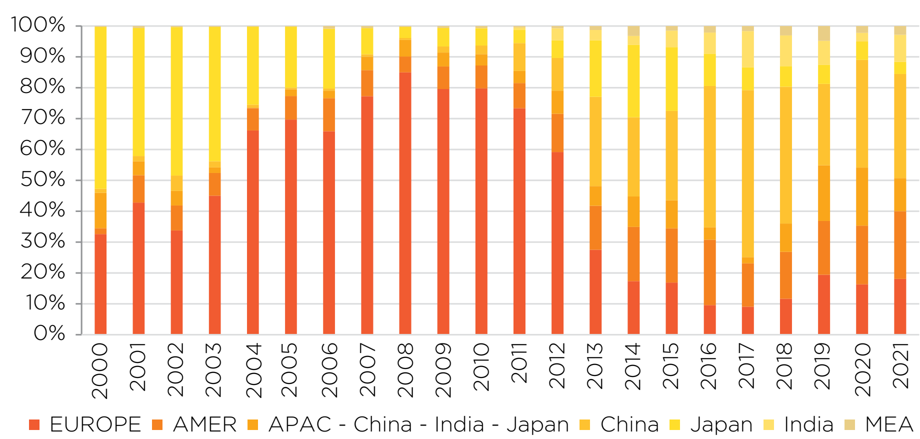
Source: BNEF, IEA, IHS, IRENA, SPE

3.2.2. Regional distribution

In the early phase of solar PV development, the on-grid market was driven by two countries, Japan and Germany – the former promoted solar through a Renewables Portfolio Standard (RPS) law, while the latter had implemented a feed-in tariff (FIT) program. In 2004, these two pioneering solar PV countries became the first to operate 1 GW of solar PV capacity.

The period from 2004 until 2011 can be considered as the first "golden age" of solar PV in **Europe,** which largely dominated the global market with an annual installation share ranging from 66 to 85% (fig. 10). During this period Germany continued its growth, while other European nations such as Italy, Spain, France and Belgium all crossed at least 1 GW of annual installations thanks to the introduction of generous feed-in tariffs. Italy even became Europe's largest, grid-connecting 9.2 GW in 2011, a performance still unmatched today on the continent. That first European solar PV boom phase came to an end after 2011 when government slashed solar PV support schemes at times European countries were dealing with political and financial turmoils of the debt crisis, among other factors. Following this, the European market decreased from 21.9 GW in 2011 to just 7 GW in 2016, leaving the space for other regions to take the driver's seat.

Fig 10. Regional shares of annual solar PV deployment, 2000-2021



Source: BNEF, IEA, IHS, IRENA, SPE

While Europe neglected solar PV for most part of the second decade of this century, the **Asia-Pacific (APAC)** region emerged as the new undisputed leader in global solar PV deployment, driven by three of its major economies – China, India and Japan.[1] Together, in 2013, the three installed 89% of the 21.6 GW that the APAC region brought online, and 51% of the 37.9 GW installed worldwide.

Since 2013, APAC remains the premier solar PV region, and has continued to keep more than half of the global market share until today. During that time, the regional breakdown for solar PV market shares has remained mostly unchanged – the solar world is largely dominated by China, which installed a new annual installation record of 54.8 GW in 2021. China accounted for more than one third of the global annual installation five times between 2016 and 2021.

The removal of module import duties in the EU and improved policy frameworks resulted for **Europe** in exiting its downhill path and has experiencing a second growth phase. With an annual market of 29.4 GW in 2021, the continent reached a new record 10 years after the previous peak of 21.9 GW was achieved in 2011.

Solar PV in the **Americas** has followed a less volatile evolution showing progressive growth, mostly supported by the United States – the world's second largest market in 2021 with 27.3 GW – as well as Brazil, Mexico and Chile. Over the past 10 years, the global solar PV share of the American continent increased from 8% in 2011 to 22% in 2021 (35.7 GW).

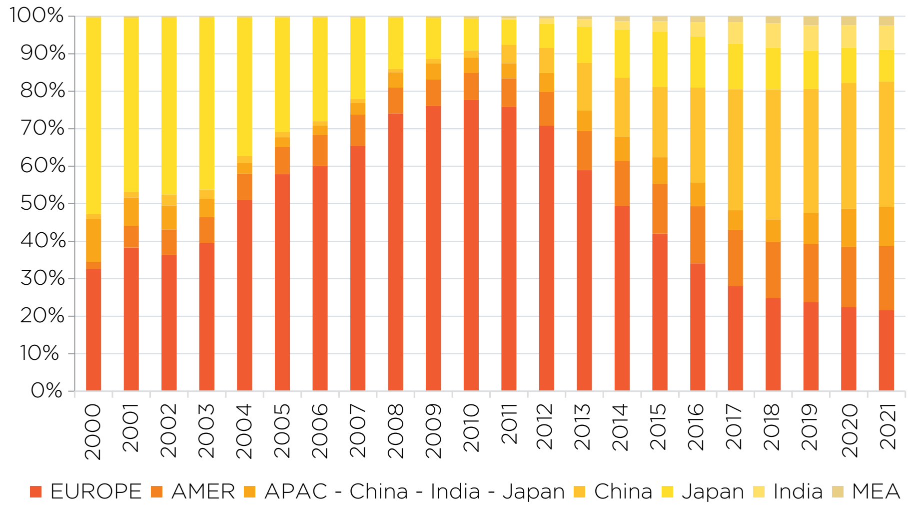
On a much smaller scale, the **Middle East and African** (MEA) market has been also slowly growing, but more volatile as demand was mostly created by government tender based large multi-GW solar PV projects on the Arabian Peninsula. In 2021, the region installed 4.7 GW, equivalent to a 3% global share.

A look at the total global operating capacities shows how Europe's inactive solar PV phase and the strong ascent of China have changed the balance of global PV deployment, while the Americas have continued their slow expansion path and the MEA region has started appearing on the solar landscape (fig 11). Today, the APAC owns a 59% share of the operating global PV fleet, with China alone controlling 34% of global capacity. Even after Europe's PV market started to grow again, in the global context it continued to lose market shares, bottoming at 22% in 2021, whereas the Americas' share increased to 17% and MEA reached 2%.

APAC region accounts for 59% of all solar PV installed capacity. Within APAC, 57% belongs to China. Europe represents 22%, the Americas 17% and MEA is a mere 2%.

[1] Due to their size, the three countries are shown separately in the graph.

Fig 11. Regional shares of total solar PV deployment, 2000-2021

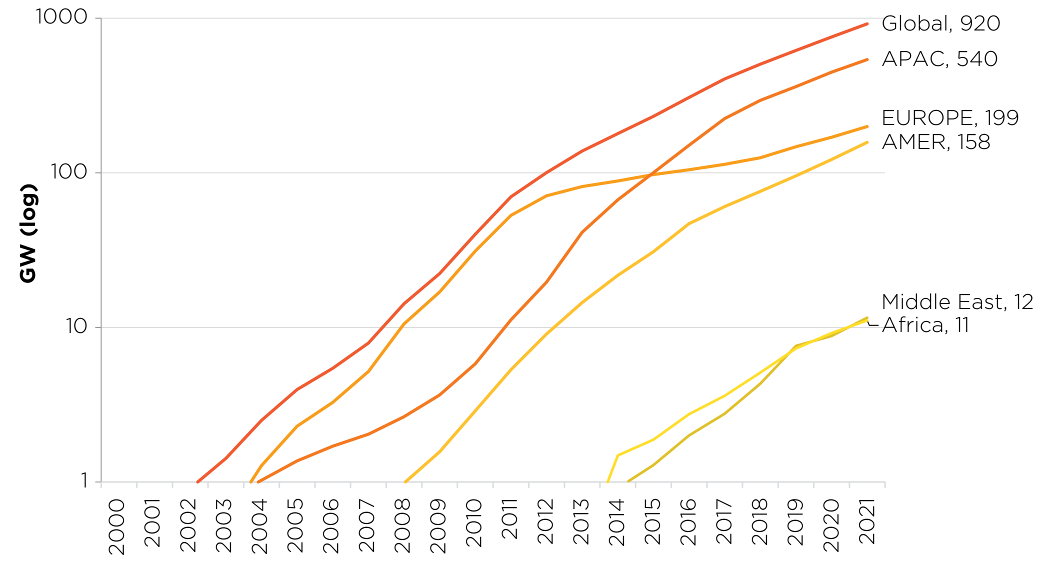


Source: BNEF, IEA, IHS, IRENA, SPE

The second growth phase of the European solar PV market until 2021 has been slower than for any other global region. As shown in Fig. 12, solar PV in Europe grew at a rapid pace until 2011, after which the curve flattened. In APAC, growth progressed more slowly in the beginning of the observed period, and started accelerating only towards the end of the first decade. At that time, solar PV started its rapid expansion in the Americas while MEA entered the solar PV segment at a much later stage, around 2014

The global solar PV CAGR between 2019-2021 is 22%. AMER is the fastest growing region with a 28% CAGR. Middle East and Africa both have a CAGR of 23%. APAC follows with 22%, while Europe is lagging behind with 16%.

Fig 12. Cumulative solar PV deployment by region, 2000-20212021



Source: BNEF, IEA, IHS, IRENA, SPE
Note: the vertical axis uses a logarithmic scale.

3.2.3. Segmentation

Table 1 - State of solar PV segmentation at the end of 2021

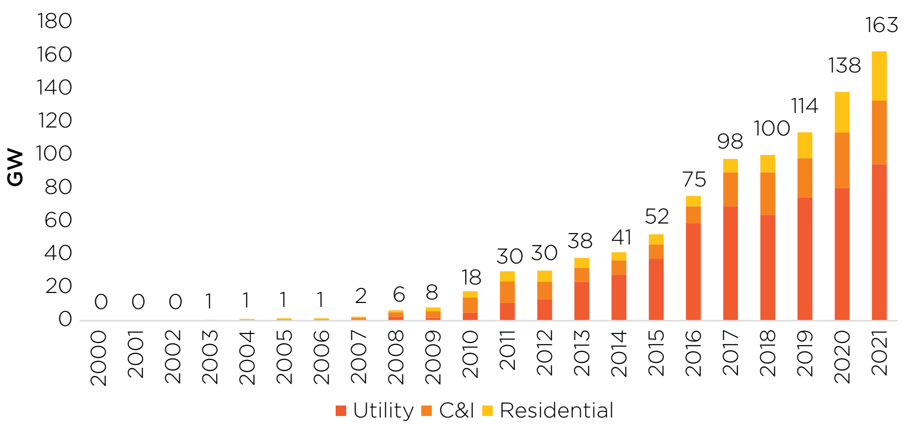
	Residential	Commercial	Utility-scale
Annual (163 GW)	18%	24%	58%
Cumulative (920 GW)	15%	24%	61%

Table 2 - Compound Annual Growth rate of annual addition per segments in the period 2019-2021

	CAGR - 2019-2021
Residential	38%
Commercial	28%
Utility	13%
Global	20%

At the start of the modern solar PV era, deployment was driven by the rooftop segment, especially small-scale residential systems, later overtaken by commercial and industrial (C&I) applications. From 2000 to 2005, rooftop solar PV accounted for more than 90% of annual global capacity. Only as of 2006, utility-scale installations started gaining traction, continuously taking away shares from the rooftop segment. In 2013, new utility-scale solar PV installations outperformed the rooftop segment for the first time, reaching a 62% share of annually added capacities. In the following year, the utility-scale segment has kept its strong market dominance, providing an average share of 67% of annual installations per year (see fig 13).

Fig 13. Annual global solar PV deployment per segment, 2000-2021

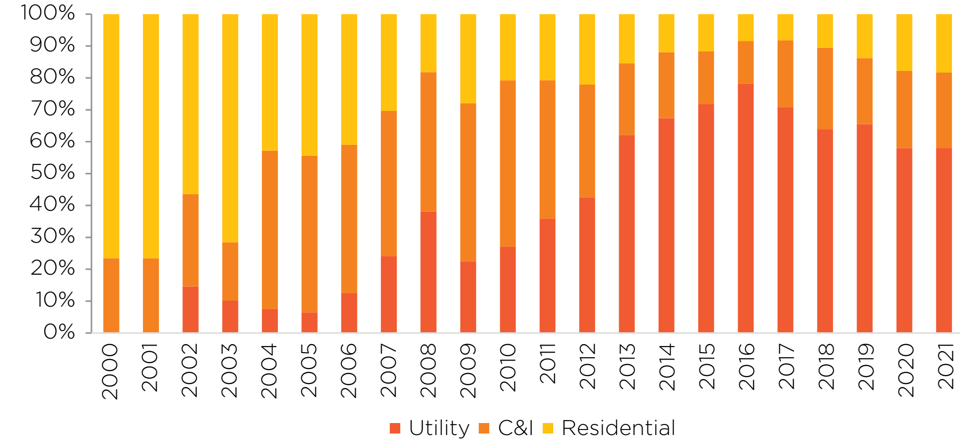


Source: IEA, Bloomberg, IHS

Today's emerging solar PV markets tend to follow the opposite evolution – they start with the deployment of large-scale installations through tenders and auctions, allowing a rapid and cost-efficient development of large solar capacities. This is simpler than creating a high-volume rooftop solar market that requires first some time to establish a functioning legislative framework and create awareness for solar among citizens and businesses. But the big advantage of rooftop solar over large-scale power plants is its very high public acceptance as the systems can be attached to or integrated into buildings, thus avoiding any conflicts related to additional land use for solar system deployment. Moreover, being installed very close to the point of consumption, rooftop solar offers the benefit of reducing grid costs and developing a decentralised energy system based on prosumers.

Although the growth in each solar PV segment continues its upward path in absolute terms on a global level, relative shares have seen some variations in recent years. After peaking at 78% of total annual installations in 2016, the utility-scale segment's market share decreased to 58% in 2021, which has several reasons: First, utility-scale projects are generally much more sensitive to price fluctuations than rooftop solar projects. The price increase for PV system components, installation cost, logistics that took place in 2020 and 2021 due to the pandemic and resulting supply chain issues resulted in delays or cancellation of projects across the globe. Second, as a result of increasing power prices residential and C&I customers have been turning increasingly to solar rooftops as a means to reduce their electricity bills.

Fig 14. Share of annual solar PV deployment per segment

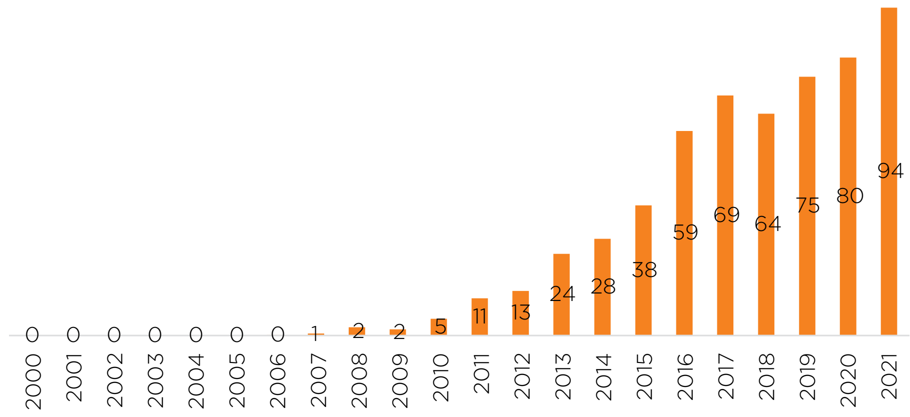


Source: IEA, Bloomberg, IHS

3.2.3.1. Utility-scale

Despite losing market share in recent years, the annual global utility-scale market reached a record level of 92 GW in 2021, a 18% year-on-year growth and a 105% CAGR in the period 2000-2021 (see Fig. 15).

Fig 15. Annual global utility-scale solar PV installed capacity, 2000-2021



Source: IEA, Bloomberg, IHS

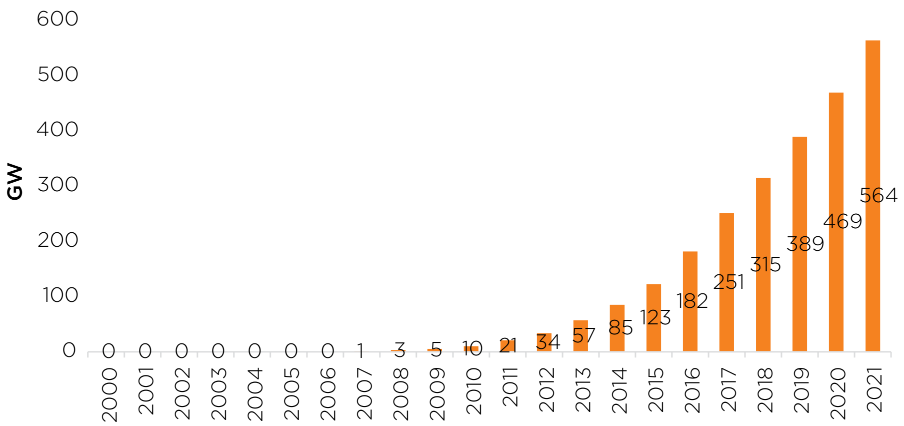
Utility scale solar often is still the lowest cost power generation source – and driven by tenders, corporate PPAs, wholesale markets, demand has continued to grow for large-scale ground mounted solar PV projects.

While China remained the uncontested global leader in that segment in 2021, installing 25.6 GW, the major drivers of utility scale solar were the United States and India. Unlike in China, where more solar was installed on rooftops in 2021, the US ground-mount segment accounted for 19.7 GW equal to 72% of annual installed capacity in the country. In India, the utility-scale segment was even more dominant – new PV power plant additions of 11.5 GW captured 81% of the total PV market, following the previous years' trend. Large-scale solar PV in the US is driven by a combination of attractive tax credits, Renewable Portfolio Standards and increasingly corporate PPAs, whereas India's pull for this segment comes from government tenders. Latin America's major solar markets, except for Brazil, are also governed by utility-scale solar systems, and mostly built as part of tendering schemes.

The same is true for most countries in Asia, Middle East and Africa. Ground-mount solar PV's significance differs in Europe; in the vast majority of countries its share is smaller than for rooftop systems, the only exceptions with clearly dominant utility solar PV segments in 2021 were Spain and Denmark. Utility-scale solar PV in Europe has been primarily incentivized by tenders, but interest in PPAs and merchant projects has grown and led to multi-GW project development pipelines Spain, Portugal and Italy, most of which is stuck due to permitting or grid-connection issues.

Thanks to its cost competitiveness and driven both by tenders and PPA/wholesale markets in a quickly growing number of geographies, solar PV utility-scale's total operating capacity has surpassed the 500 GW mark in 2021 (Fig. 16). With 564 GW installed by the end of last year, the global solar PV power plant fleet has grown over 50 times since 2010.

Fig 16. Cumulative global utility-scale solar PV installed capacity, 2000-2021



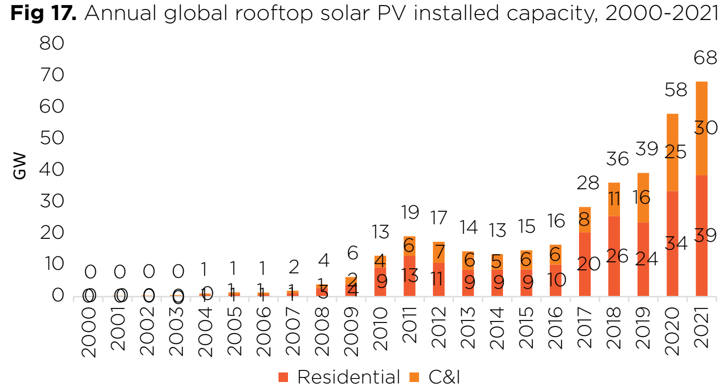
Source: IEA, Bloomberg, IHS

3.2.3.2. Rooftop Solar PV

The global rooftop PV market absorbed 68 GW in 2021, a 18% growth from the 58 GW installed in 2020 (see Fig. 17). Though the pace was slower than in the previous year when installed capacity increased by 48%, the rooftop solar PV's growth trend remained intact in 2021 as it was level with the overall global solar PV growth trend.

Like in 2020, the main contributor to rooftop PV in 2021 was China. Traditionally a utility-scale market, as of recently the country has been experiencing very strong demand for rooftop PV, triggered by regional programmes and solar's attractive business proposition. 2021 not only meant a new installation record for China, it was also the first year, the country installed more solar capacity on roofs, 29 GW, than through ground-mounted systems, 24 GW.

Fig 17. Annual global rooftop solar PV installed capacity, 2000-2021



Source: IEA, BNEF, IHS

Next to China, other markets with strong solar PV rooftop segments have emerged recently, often for different reasons. Notable in Europe are the rather new solar rooftop markets in Spain and Poland. Spain, one of the continent's sunniest countries reigned by tenders and PPAs for ground-mounted PV power plants in the past, has been able to unleash growth in the distributed solar segment only after its 'Sun-Tax' was abolished in 2018 – a fiscal scheme that highly taxed PV installations for electricity produced and consumed; the driver for rooftop solar is self-consumption, which turned the country into Europe's fourth largest rooftop market with 1.4 GW installed in 2021. On the other hand, Poland had an attractive net metering scheme in 2021, which provided the grounds for 3.2 GW, representing a 19% market share of the 2021 EU's rooftop segment. A high retail power price environment is a feature of many European countries, which explains the overall large share of rooftop solar PV of 61% in 2021 as residents increasingly turn to solar PV to reduce their electricity bills.

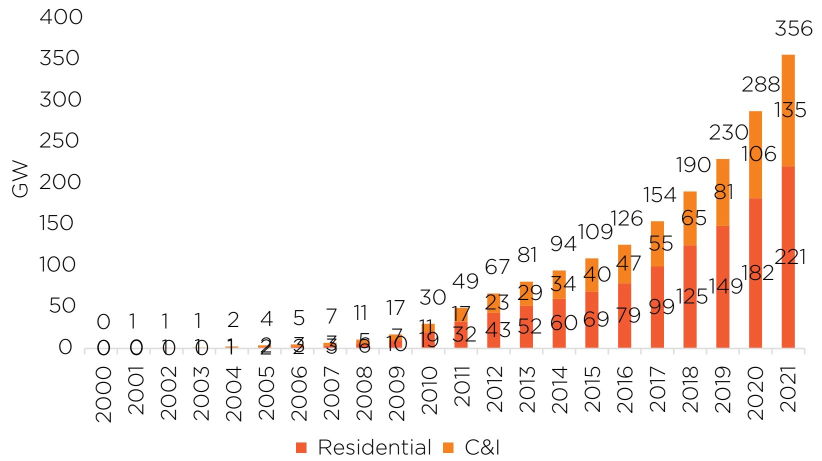
In Americas, the two largest solar PV markets both are characterized by strong solar PV rooftop solar demand – and both rely on the same incentive scheme, net metering. While rooftop solar PV was responsible for 5.5 GW in 2021, or about a quarter of the world's second largest market USA, in Brazil the distributed share of solar PV even dominated, covering 72% of the market. Brazil had been experiencing a surge of rooftop solar installations to a total of 3.8 GW in both the residential and C&I segment after its net metering law was updated, now ensuring that new PV installations up to 5 MW can benefit from the net-metering scheme until 2045.

The success of rooftop solar across the board is based on solar PV's versatile nature – both economic and energy security play key roles for energy users striving to become prosumers. However, the rooftop segment comprises both small-scale solar PV systems for households (up to 10 kW) and larger installations for commercial & industrial (C&I) applications. As the needs of the investors/operators in the segments are quite different, so are the policy drivers and barriers as well as the underlying business models.

The total installed solar rooftop capacity increased by 24% to 356 GW by the end of 2021 from which the bulk, 221 GW, comes from C&I installations and 135 GW from residential systems (Fig. 18)

The growth of the annual residential market jumped from 16 GW in 2019 to 25 GW in 2020, reflecting the Chinese growth whose market accounted for almost 50% of new global installations in 2020.

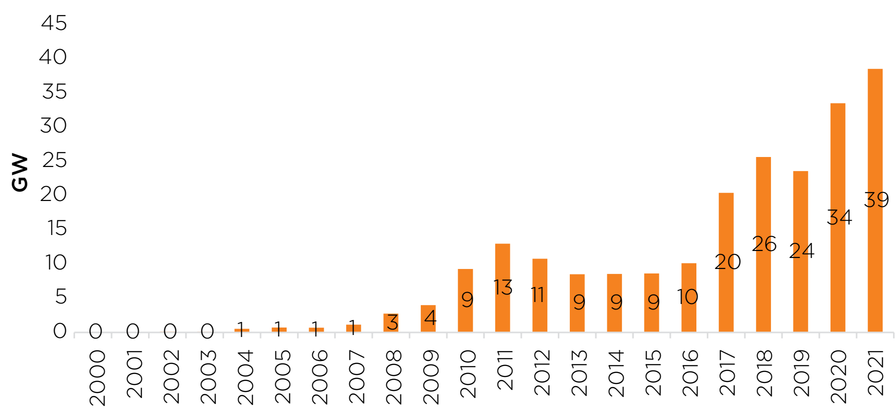
Fig 18. Cumulative global rooftop solar PV installed capacity, 2000-2021



Source: IEA, BNEF, IHS

The C&I segment took center stage from the start of the solar PV rooftop evolution at the beginning of the century, when small businesses, including farmers, very early understood the attractivity of PV feed-in tariff in Germany. While globally C&I solar PV has been continuously seeing larger capacities being installed than its residential peer, it experienced slower and faster growth phases as a consequence of changing policy frameworks. However, in 2021, 39 GW of C&I PV systems were installed worldwide, a 15% growth compared to the 34 GW installed in 2020 (Fig 19).

Fig 19. Annual global C&I solar PV installed capacity, 2000-2021

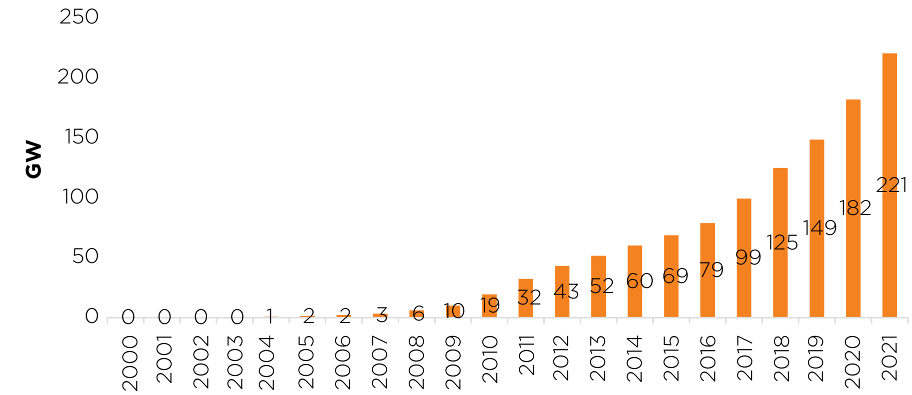


Source: IEA, BNEF, IHS

The first C&I growth phase came to an end in 2011, at a time Europe's first solar PV growth phase concluded. The major European solar markets had slashed their generous feed-in tariff incentive programmes during a very difficult financial and economic period stemming from the 2008 economic crisis. The second drop for C&I lasted only one year – in 2019, when the world's largest solar PV market China dipped by 11 GW to 33 GW. A large part of that dip was carried by the commercial segment, which fell from 17 GW in 2018 (about 60% of annual global C&I installations) to 5.6 GW in 2019 (about 25% of the global C&I market).

On a cumulative basis, however, the C&I segment experienced continuous growth. The total operating C&I fleet reached 221 GW in 2021, only four years after the 100 GW mark was passed in 2018 (Fig. 20).

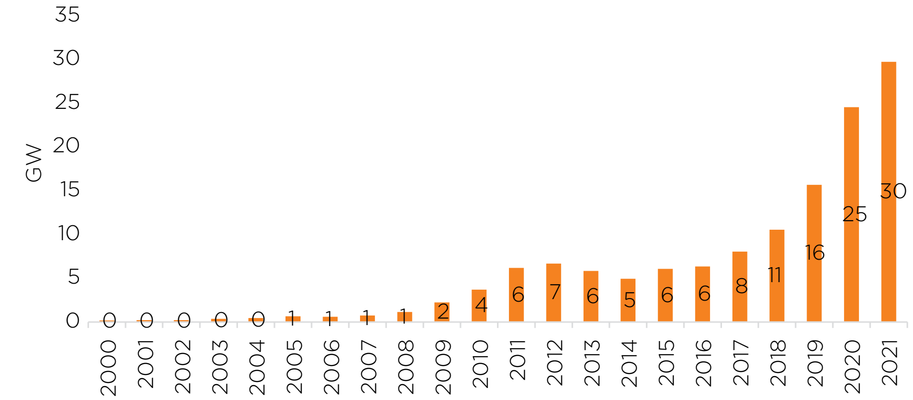
Fig 20. Cumulative global C&I solar PV installed capacity, 2000-2021



Source: IEA, BNEF, IHS

Developments in the residential solar segment have followed a similar pattern as for C&I but at lower installation levels. In 2021, 30 GW of solar PV were deployed on homes (Fig. 21). In the past residential solar was primarily driven by Western European markets, in the meantime, the geographic distribution of relevant residential PV market has widened across the world. The reason for residential solar PV's exceptional performance in 2021 can be attributed to China, which introduced a favorable scheme that led to the installation of around 21 GW of residential PV systems last year, equal to 70% of the entire segment.

Fig 21. Annual global residential solar PV installed capacity, 2000-2021



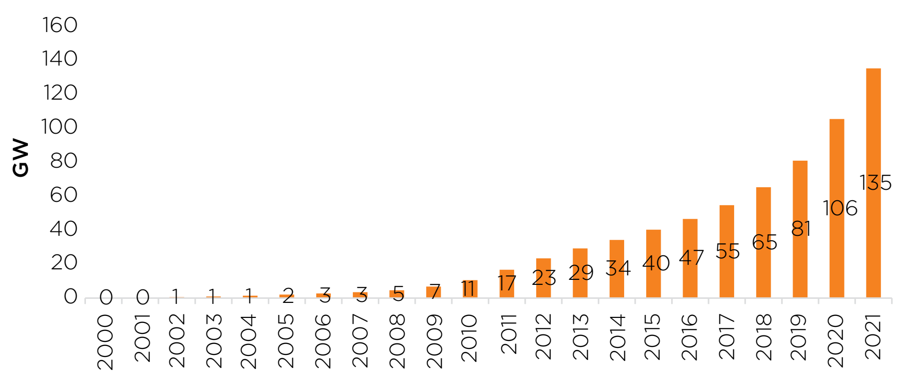
Source: IEA, BNEF, IHS

The reason for residential solar PV's exceptional performance in 2021 can be attributed to China, which introduced a favorable scheme that led to the installation of around 21 GW of residential PV systems last year, equal to 70% of the entire segment.

Although residential rooftop solar PV mostly followed the deployment pattern of C&I, it experienced a more stable growth as financial investment considerations for households are very different than for businesses. Companies are much more attentive to payback times to justify their investments, and therefore are more susceptible to changes in the support framework. By contrast, households are somewhat less dependent on financial incentives, as part of this segment can be driven by different motives (e.g., energy independence, climate concerns) than purely financial considerations. While residential solar was also affected by the end of the European feed-in tariff schemes in the early 2010s, the market contraction has not been as pronounced as for C&I solar. Moreover, the 2019 demand drop in China was hardly felt on a global level in the residential segment as this part of the Chinese market was comparatively small at that time.

With homeowners in China, the US and many other markets around the world increasingly embracing the advantages of rooftop PV, the global fleet of residential PV systems reached 135 GW in 2021, an amazing result when considering that these systems are typically less than 10 kW in size (see Fig. 22). The global cumulative residential PV capacity has grown more than tenfold compared to ten years ago.

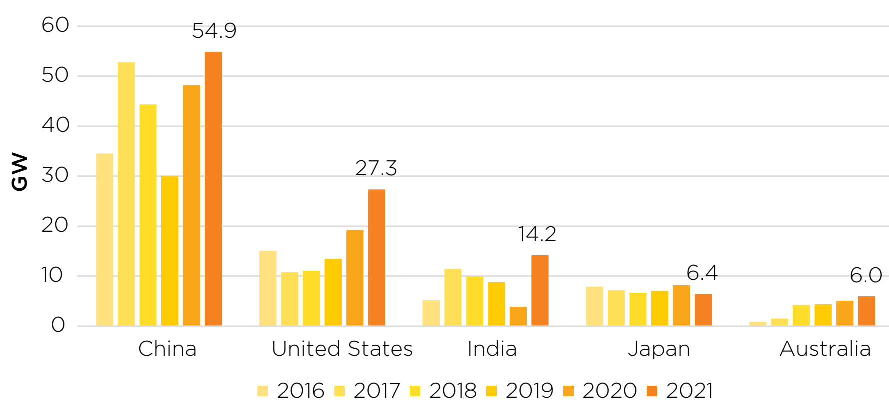
Fig 22. Cumulative global residential solar PV installed capacity, 2000-2021



Source: IEA, BNEF, IHS

3.2.4. Top 15 countries

Fig 23. Top 5 annual solar PV addition 2016-2021 (2021 ranking)



Source: SPE

For the ninth year in a row, China remained the world's largest solar PV market, growing newly capacity additions by 14% to 54.9 GW in 2021, finally breaking its earlier record of 52.8 GW in 2017. The restructuring of its solar policy framework from uncapped feed-in tariffs to auctions and subsidy-free systems has been accomplished, the signs are set for further strong growth. Around 29.3 GW (53%) of the capacity installed in 2021 came from distributed solar PV and 25.6 GW (47%) from centralized solar. The strong performance of the distributed segment in 2021 was mainly based on government incentives for residential systems that were available for the last year. As a result, the market segment for rooftop solar PV grew by 113% from 2020, and, for the first time, contributed more than 50% of the annual installed capacity. At the same time electricity price hikes have triggered a C&I solar boom well. China continues to be the outstanding global solar leader, installing more than all other four following countries combined. The record installation volume in 2021 brought China's total PV power generation fleet to 308 GW, a 22% increase from 253 GW in 2020. This trend is very likely to go on, and most analysts now expect the country to add between 75-90 GW in 2022. China not only remains the biggest PV market, it also dominates the world in PV manufacturing and has huge capacity expansions underway all along the value chain (see more details in ISA Solar Technologies Report).

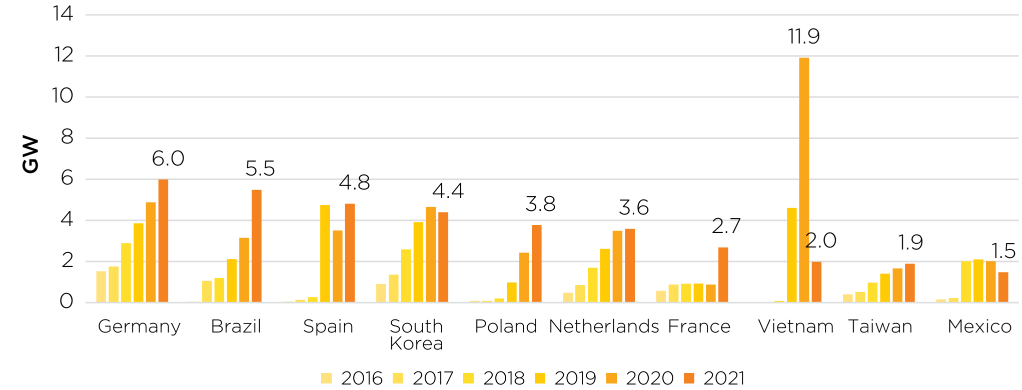
The United States remained on the second place in 2021, after installing a new record capacity of 27.3 GW. With a high 42% growth rate, it basically kept the level of the previous year – in 2020, the US solar PV market grew by 43% to 19.9 GW. This latest solar PV additions has led the country's solar PV power generation fleet to 122.8 GW, 28% higher than in 2020. The bulk of newly installed capacity took place in the utility-scale segment, 19.7 GW, representing a share of 72%. The strong development of utility solar PV in Texas brought the state's new additions in 2021 to 6 GW, for the first time surpassing long-time US leader California which installed 3.6 GW. The following states were #3 Florida (1.6 GW), #4 Virginia (1.4 GW), #5 Georgia (1.2 GW) and #6 Indiana (1.1 GW). New installation record could also be seen in the residential segment at 4.9 GW, and C&I at 2.7 GW. The US' main driver for solar PV across the board has been an investment tax credit (ITC), which has been on a digressional path, reaching 26% in 2020/21, but has been extended by Congress in August 2022 for 10 years and raised to 30% until 2032.

India stepped up in 2021 and installed a new record of 14.2 GW to regain the third spot which the sub-continent held back in 2019. In 2020, it had dropped out of the top 5 following a disappointing year in which only 3.9 GW was installed. The impressive 264% year-on-year growth in 2021 led to a total installed solar PV capacity of 60.1 GW and marks the end of the recent downward trend. The utility-scale segment accounted for the vast majority of solar PV installations while the rooftop segment only represents 6.5 GW of the country's operational fleet.

Japan held on to its 4th position in the global ranking in 2021 despite a shrinking market. It installed 6.4 GW, which is 1.8 GW less than in 2020 and about 1 GW below its 2016-2020 average deployment levels. A global pioneer for on-grid solar, Japan's solar capacity have been on a constant downward path (except for 2020) since its 10.8 GW market peak in 2015. High cost, extensive permitting procedures combined with grid constraints have delayed the transition from a feed-in tariff scheme to tender, merchant and self-consumption environment.

Australia was again ranked fifth in 2021 after adding 6 GW new solar PV capacity. Since 2014, the country has been following a slow but steady upward path, installing every year a little more than the previous year and a 33% CAGR. Despite its vast space and the low density of population, the residential rooftop segment has been the base for Australia's solar PV boom. In the past, backed by local incentives, and now mostly self-consumption, rooftop solar reached 3.2 GW, a 53% share in 2021. With many announcements for multiple GW green hydrogen projects and a new government that put climate change on high on the agenda, there is high expectations for a quickly growing PV power plant segment in the future as well.

Fig 24. Top #6 to #15 annual PV addition 2016-2021 (2021 ranking)



Source: SPE

On 6th place, Germany was the top European solar PV market in 2021. Its annual installation volume improved by around 1 GW to 5.9 GW. In terms of cumulative solar PV capacity, the country now ranks 4th, operating a total of 60 GW. Rooftop solar PV remains the foundation of the German market growth, nearly two thirds of new capacity additions in 2021 was attached to buildings. The solar segment has been well supported by regular tenders for systems above 750 kW as well as a well-established premium feed-in tariff scheme. With the second highest retail electricity prices (0.3234 €/kWh) in Europe just behind Denmark (0.3448 €/kWh), solar self-consumption in combination with the premium feed-in tariff has been the winning formula for Germany rooftop solar in recent years, with business being the main group investing in solar systems – in 2021, the C&I share was 33%. Tenders and a quickly increasing demand for corporate power sourcing have led to a thriving utility segment in recent years as well. With the world's most ambitious solar PV target of 215 GW by 2030 to meet its climate targets, and an unseen energy crisis in the EU ignited by the Russian invasion in Ukraine, solar PV in Germany is set to grow very strong in the coming years.

Brazil is the first – and only – country from Latin America in the top 10 solar markets. It entered straight at the 7th place thanks to 5.5 GW installed in 2021, which meant 72% growth compared to 3.2 GW added in 2020 and almost doubled total installed capacity to over 13 GW. Although Brazil organizes regular tenders, in which solar often wins, the market is governed by distributed solar applications. Carried by a favorable net-metering scheme for systems up to 5 MW, now for three years in a row rooftop solar has prevailed over ground-mounted solar applications, reaching shares ranging from 69% in 2019 to 72% in 2021. As the net material scheme was recently extended, the rooftop segment will continue to soar in Brazil.

Spain has been progressively climbing up the solar rankings, moving up from 9th place in 2020 to 8th place in 2021. With newly added capacities of 4.8 GW in 2021, the country has experienced 37% year-on-year growth over the 3.5 GW installed in 2021. Spain distinguishes itself by a gigantic development pipeline of 100 GW+ of unsubsidized solar projects of which only small portions come online year after year as permitting issues and grid constraints are delaying faster project completions. In 2021, the Spanish PPA market represented around 70% of newly installed capacity. On the other side, the distributed self-consumption segment is also quickly evolving, though from a very low level as a prohibitive tax for solar rooftops applications was only removed in 2020. However, in 2021, the share of rooftop solar for Spain's newly installed solar PV capacity already reached 30%. As the Spanish government approved a self-consumption strategy in 2021, the prospects are very good for distributed solar in Spain.

After 5 years of consecutive growth, South Korea's solar PV market slowed down by 6%, installing 4.4 GW in 2021, which still remains the second-best year for the country. More than 90% of the solar PV capacity in the country was installed under the Korean Renewable Portfolio Standard, which requires utility companies with generation capacities over 500 MW to supply between 6% and 10% of their electricity from renewable source by 2023. Due to its high population density and mountainous landscape, South Korea has been mostly focusing on distributed solar PV applications; the solar rooftop share of its total installed capacity was 14% in 2020. In addition, the country has been looking into innovative solar technologies such as floating PV. The development of two gigantic floating PV power plants with 2.1 GW each have been announced by Korean Ministries in 2019 and 2021.

The top 10 is completed by second European country, Poland, which is a newcomer to this list, taking the spot from the Netherland, which dropped to the 11th place. Poland is Europe's latest big solar market and installed 3.8 GW in 2021, a 56% improvement over the 2.4 GW grid-connected in 2020. The country's solar development has been strongly supported by a favorable net-metering scheme that ended in 2022 as well as subsidy programme covering up to 50% of installation costs and capped at 5,000 PLN (US$997) per PV systems between 2 kW and 10 kW. For utility-scale system, representing only 15% of the newly installed capacity in 2021, strong growth is expected from national tenders and high demand from the C&I sector to hedge against rising electricity prices as a result of Europe's fossil and nuclear energy crises.

Following the top 10, Netherlands (3.6 GW) takes the 11th spot supported by the rooftop segment and the SDE++ subsidy scheme, France (2.7 GW) lands on place #12 after tripling its annual installation in order to try to achieve the target announced in its Multi-Annual Energy Program (MAEP). Vietnam (2 GW) fell from the 3rd place to the 13th place. After the unforeseen surge in 2020 and 11 GW installed, the country suffered from the termination of the generous feed-in tariff and the lack of long-term plan for renewable energy. Finally, Taiwan (1.9 GW) and Mexico (1.5 GW) take the 14th and 15th spot in the largest solar PV market in the world in 2021. Taiwan is following a sustained growth path whereas Mexico is currently struggling with internal political issues linked to its energy sector.

Looking at the top 10 solar market between 2017 and 2021 (Table 3), it can be observed that while the top spots are hardly changing, the lower ranks are much more dynamic. Throughout this period, China has stably kept the top spot, while the US has been the second largest market since 2018. India landed in the podium every year except 2020, when the market experienced some turbulence due to the financial conditions of some regional actors, while the mature Japanese market reached a stable installation level and kept its fourth place since 2017. Other established markets like Germany and Australia appear in the top 10 in every year, while positive or negative changes in framework and investment conditions determined the addition or removal of the other countries in the list. The performance needed to enter the top 10 club increased from 0.9 GW in 2017 to 3.9 GW in 2019. The impact of COVID-19 on solar markets can be seen in the last two years, where the annual deployment required to enter the top 10 remained at 3.5 GW and 3.8 GW respectively.

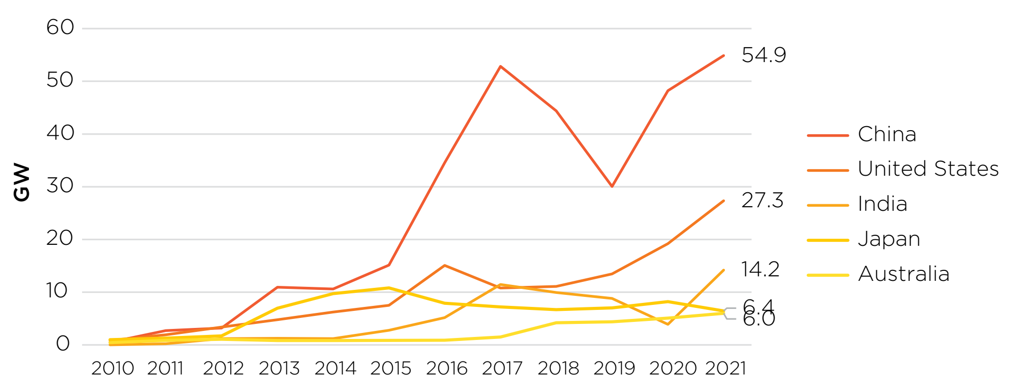
Very little movement in the top 4 markets over the last 5 years

	2017	2018	2019	2020	2021		2017	2018	2019	2020	2021
1	China	China	China	China	China	6	Germany	Germany	Vietnam	Germany	Germany
2	India	United States	United States	United States	United States	7	Australia	South Korea	Australia	South Korea	Brazil
3	United States	India	India	Vietnam	India	8	South Korea	Mexico		India	Spain
4	Japan	Japan	Japan	Japan	Japan	9	Brazil	Netherlands	South Korea	Spain	South Korea
5	Turkey	Australia	Spain	Australia	Australia	10	United Kingdom	Turkey	Germany	Netherlands	Poland
						Annual deployment required to enter top 10	0.9 GW	1.7 GW	3.9 GW	3.5 GW	3.8 GW
						Number of countries with a market above 1 GW	0.9 GW	1.7 GW	3.9 GW	3.5 GW	3.8 GW

Source: SPE

Figure 25 displays the evolution of the solar market in last year's top 5 countries in the timeframe 2010-2021. Despite the variability stemming from the effects of its support framework restructuring, China has consistently remained above the other countries since 2013 and has reached a different order of magnitude compared to its peers. With a 44% CAGR in the period 2010-2021, China is also the country with the highest market growth on average on this list. The United States, the second largest market last year, is also ranked #2 in terms of average market growth, with a 35% CAGR between 2010-2021. The US market has grown in a stable manner during this timeframe, adding more capacity than the year before in 10 out of the 11 years considered. India's market growth has been more oscillating: the record 14.2 GW installed in 2021 finally reversed a declining trend that had started back in 2017. Nevertheless, its 27% CAGR between 2010-2021 shows how rapidly the market has evolved from almost zero at the beginning of this period. Despite their equal 17% CAGR, the solar markets in Japan and Australia are quite different. The former, one of the first solar pioneers, reached its peak installations in 2015 (10.8 GW) and has been consistently below the 10 GW mark ever since. The latter has undergone a slow but steady growth that resulted in the record 6.0 GW installed in 2021.

Fig 25. Top 5 countries annual solar PV addition



Source: SPE

3.2.5. Watt per capita of solar PV

Turning the scope of analysis to other metrics allows to highlight different relevant disparities between and within regions. The Watt per capita (W/c) metric, in particular, enables a direct comparison of countries of different size and depicts a very different picture of the current solar world. Despite their leadership, none of the top 3 markets of 2021 per installed capacity – China, United states, and India – figure on the W/c top 10 (see Table 4). On the contrary, Australia, Germany, Japan and South Korea have the privilege to figure in all top 10: Watt per capita, cumulative installations and annual installations. Netherlands, as the number 2 in Watt per capita in the world and the first European country, lands just at the door of both top 10 cumulative and annual installation.

In 2021, the global solar PV W/capita increased by 20 points to reach 119. Europe increased by 43, AMER by 35, APAC by 19 and MEA by 3.

This ranking particularly highlights smaller countries which perform very well at the national level. This is especially the case of Malta and Luxembourg, respectively top 6 and 7 with 467 and 435 W/c – more or less the equivalent of a solar module per person – while being far from the top 50 in terms of absolute installation. Other nations fall somewhat in the middle, such as Belgium and Denmark which find themselves near the top 20 in absolute installations and in the top 10 of capacity per inhabitant.

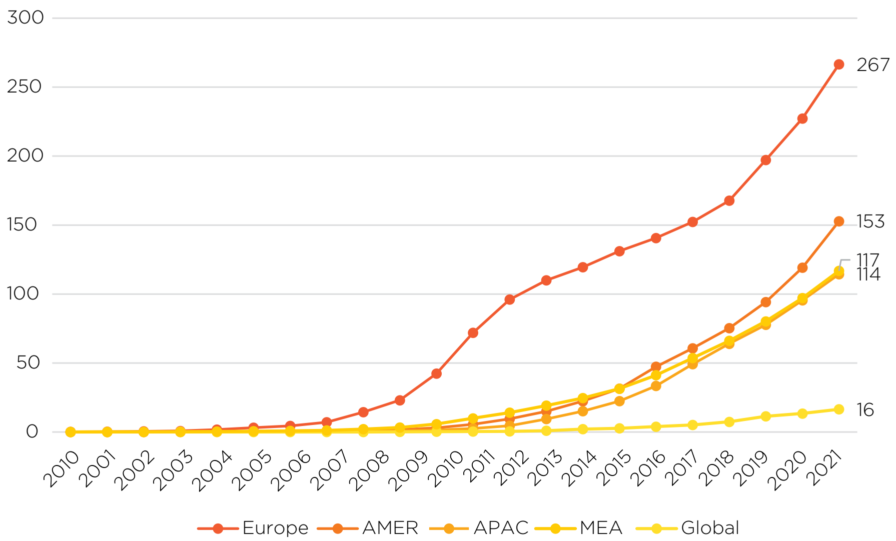
Table 4 : Ranking of countries in Watt per capita, cumulative PV in 2021, annual PV in 2021

	W/c	Country	Ranking per cumulative installation 2021	Ranking per annual installation 2021
1	1049	Australia	6	5
2	815	Netherlands	12	11
3	722	Germany	4	6
4	616	Japan	3	4
5	599	Belgium	20	30
6	467	Malta	75	93
7	435	Luxembourg	65	59
8	426	Denmark	33	23
9	416	South Korea	8	9
10	412	Switzerland	25	32
...				
15	369	United States	2	2
25	212	China	1	1
28	202	France	13	12
58	43	India	5	3

Source: SPE

Strong differences also appear on a regional basis. While the APAC region has more than three times Europe's capacity, the latter is ahead by a large margin when looking on a per capita basis, with 267 W/c compared to 114 W/c for APAC (see Fig. 26). It is also interesting to note than Europe has always been the leading continent and that, in 2021, its annual increase in W/c stood at 39, an all-time high for the sector. The AMER continent came close to it in 2021 as well with an annual increase of 34 watt/capita.

Fig 26. Watt per capita solar PV by region, 2000-2021



Source: SPE

The Netherlands is having the sharpest growth of the continent: from 173 W/c in 2010 to 815 W/c in 2021, allowing him to take the crown out of Germany (see Fig 30, next page). It can be observed that Germany and Belgium's growth was hardly hit from the low installation rates in the early 2010s. In 2010, Germany had 58 times more capacity per capita than the Netherlands. This number dropped to 6 in 2015, and the Dutch country eventually caught up and surpassed Germany in 2021 with 814 W/c to 722 W/c. The country's sharp progression is attributed to the strong support framework, which targets all segments. Policies include a net metering for residential systems and the SDE++ tender mechanism for larger C&I and utility-scale installations. While standing just outside the global top 10 markets in watt/capita, Spain has followed a fulgurant progression path. The country only added 22 watt/capita in the period 2011-2018, moving from 104 to 126. However, following three great years of PV development in 2019, 2020, 2021, the country watt per capita increase from 228, 303 and 406 at the end of 2021.

The Americas comes second with 153 Watt per inhabitant, mostly driven by the United States. The country represents 32% of the continent's population but 75% of its total PV capacity. In order to sustain growth in per capita terms, the other nations of the Americas need to accelerate their solar deployment, especially in Latin America and the Caribbean, an area that provides 63% of the continent's population but only 18% of the total PV capacity. The larger countries of South America are all lagging behind in Watt per capita: Brazil (61), Colombia (12), Argentina (23), Peru (15), Venezuela (0). Interestingly, the AMER region has experienced the highest CAGR of its Watt per capita since 2019 with a 27% average increase, while Europe grew at a pace of 17%. Still, even the top 1 of AMER, the US, cannot tie the game with any of the top 5 of Europe.

The third region, APAC, stands at 114 W/c, just below the world average of 117 W/c. The region hosts four of the 5 largest installers, but also the two most populated countries in the world, China and India, each with more than 1.4 billion inhabitants. Considering this weight in the balance, China stands at the 25th position worldwide, whereas India is 58th.

Out of the 5 largest Asian countries in Watt per capita, four of them also belong to the top 10 of largest installers. Only Taiwan stands out for not being in the top 10 – even though the country is far from being a small player on the world stage with almost

2 GW of newly installed capacity in 2021. Two countries are nonetheless showing excellence in all aspects: Australia for being in the lead of Watt per capita and in the top 10 of operating capacity, and Japan for being in the top 5 of both rankings. Their respective profiles are however very different: Australia's territory is more than 20 times larger than Japan's, while half of its population could fit in Tokyo alone. Still, it is worth remembering that solar uptake in Japan started over 20 years ago while Australia has more than tripled its W/c ratio in the last four years; from 300 W/c in 2017 to 1,049 W/c in 2021. This was made possible by a favorable regulatory regime. The Australian Renewable Energy Target requires the power grid to source a certain amount of its electricity from small-scale renewable systems (less than 100 kW for solar), while a feed-in tariff scheme supports the development of residential rooftops and several regional support schemes, such as interest-free loans for rooftop solar, are also available. In addition, for the development of large-scale solar several grants have been established and, more recently, the introduction of Renewable Energy Zones (REZ) has the potential to deploy multi-GW scale projects, with the first auction of 2022 being largely oversubscribed. Knowing that this positive deployment happened under the rule of the former conservative government, the victory of the pro-renewable Labor Party in May 2022 brings hope that the best is still to come for solar in Australia. Though policies have a paramount role to play, Australia's specific conditions are also making solar PV an obvious choice. The country has one of the highest solar irradiations in the world, and the retail electricity price has been very high for several years, making self-consumption extremely appealing for households and businesses.

Closing the group is the MEA region, with only 16 W/c and lagging significantly behind. Some noteworthy countries bringing up the regional average are Israel, which just passed the 400 W/c in 2021, and the United Arab Emirates, standing at 318 W/c. With a relatively small population of less than 9.9 million and several multi-GW scale projects in the pipeline, the UAE could be a candidate for a place in the top 10 in the coming years.

Fig 27. Top 5 countries watt per capita in APAC

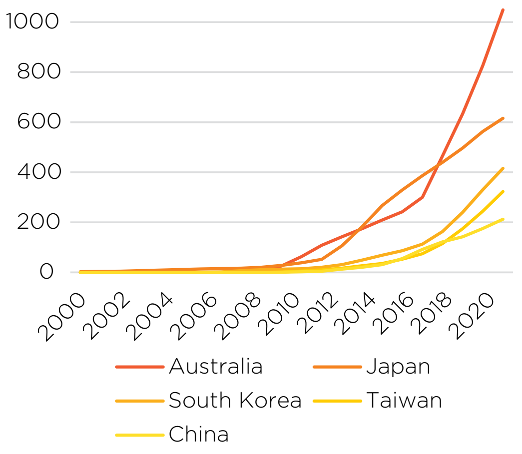


Fig 28. Top 5 countries watt per capita in APAC

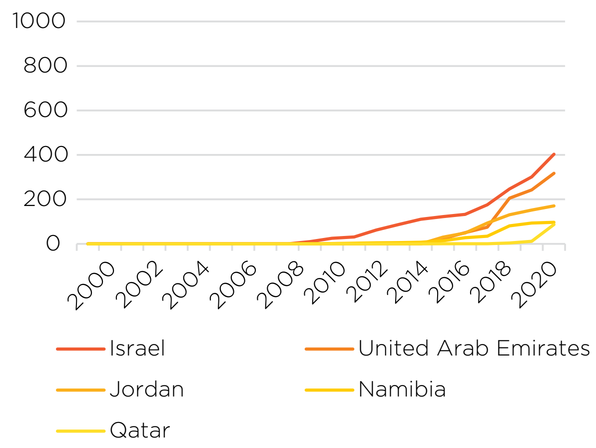


Fig 29. Top 5 countries watt per capita in AMER

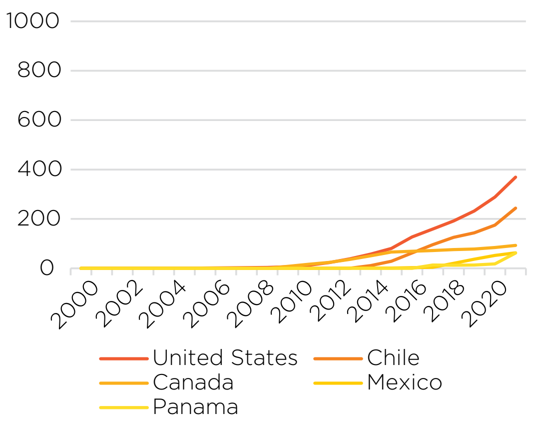
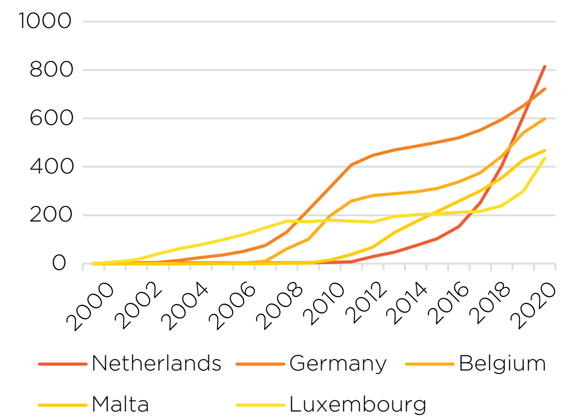


Fig 30. Top 5 countries watt per capita in Europe



Source: SPE

In conclusion, the Watt per capita metric could be used as a benchmark to assess a country's state of advancement towards high shares of solar PV penetration, to overcome the challenge of comparing countries and regions of very different sizes.

Table 5 – Number of countries in each w/capita category

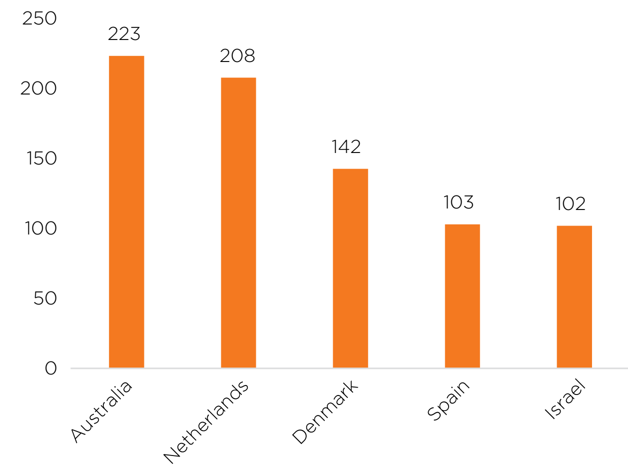
Watt per capita	Number of countries	Category
0-50	105	Below average
51-116	22	
117-300	15	Average or above average
301-500	14	Performers
>501	5	Top performer

Source: SPE

3.2.6. Annual increase in W/Capita

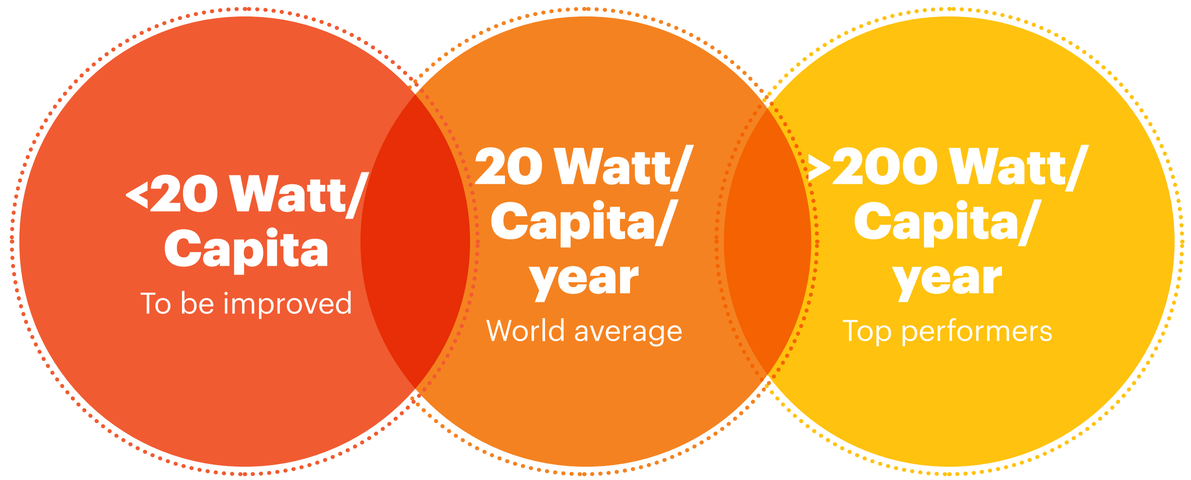
The fastest growing countries under this indicator, such as Australia and the Netherlands, have exceeded 200 W/c added in a single year, while the largest PV markets in terms of absolute capacity stood below the three digits: China performed an annual growth of 37 W/c, while additional 80 W/c were registered in the United States. Across all countries, the median is 3 w/c, implying that most of the installations worldwide are being carried by a handful of countries.

Fig 31. Net increase in watt per capita from 2020 to 2021



Source: SPE

Watt per capita added in 2021



Australia and the Netherlands respectively added 223 and 208 solar watt/capita in in 2021. Other noticeable countries are Denmark with 142 and Poland with 100. China added 37, the United States 80, India 10, Japan 53 and Germany 70.

3.3. Other solar PV applications

3.3.1. Building integrated solar PV

The building integrated solar PV (BIPV) segment is still niche in the grand scheme of solar PV. This application is nevertheless a perfect example of a policy-driven market which slowed down when the targeted support stopped.

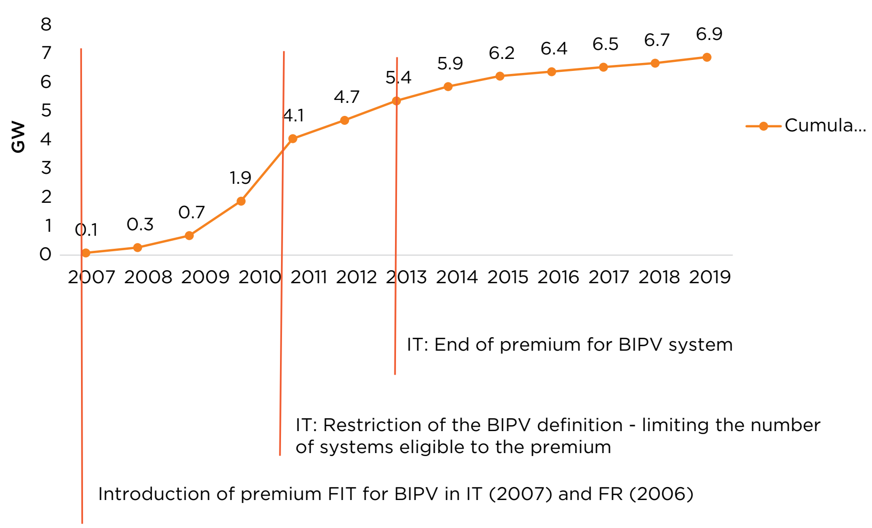
The development started a decade ago, and about half of the total capacity is installed in Europe, from which most of it in Italy and France. Indeed, both countries accelerated the development of the technology by introducing a premium on the FIT for BIPV system, in 2006 for France, and 2007 for Italy. A similar policy was introduced in Switzerland in 2009, with smaller impact on the absolute deployment. Starting from when premiums were implemented, it took a couple of years for the market to really take off in 2010-2011, with annual installation of 1.2 GW and 2.1 GW (see Fig 32).

In 2011, the Italian definition of BIPV became stricter and limited the amount of installation eligible for the premium FIT. This had a negative impact on the European market and created a slowdown in installation after 2011. After 2013, the specific premium for BIPV was completely removed in Italy, which further decelerated growth. The overall same development occurred in France, with no further distinction between BIPV and a typical residential installation after 2018.

Now, BIPV has reached technological maturity. Given that building around the world are responsible for around one-third of the final consumption and 15% of CO_2 emission, increasing the share of BIPV in the building stock would reduce the ecological footprint of cities, create local jobs, and improve the quality of life of many citizens. The potential for this flexible technology is enormous and still untapped. In Germany alone, the Fraunhofer institute estimates that BIPV could add 1 TW in the country. This is around 16 times more than what is currently installed, and more than 4 times the 215 GW solar PV target for 2030.

Transforming BIPV into a mainstream construction material for building roofs and facades would be a game changer for cities to reach carbon neutrality, without using any land. This change can also be enhanced by rooftops mandates and regulation to impose BIPV systems on new buildings **or to, at least, make solar ready buildings envelop, e.g. prepare the buildings for solar PV to be easily installed at a later stage.**

Fig 32. BIPV market in Europe 2007-2019



Source: Becquerel Institute, University of Applied science and Arts of Southern Switzerland

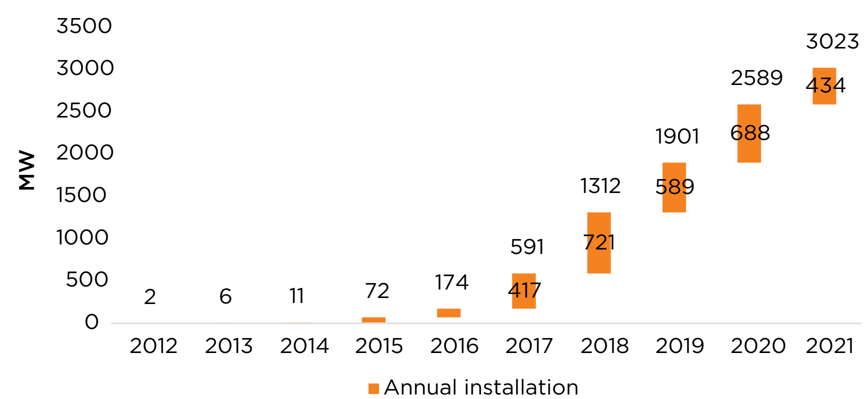
3.3.2. Floating PV

Floating PV is not so much a niche technology anymore, although there is less installed capacity than BIPV (see Fig. 33). The reason for it not being a niche is that several countries are now appreciating the benefits of not competing for land with agricultural or industrial activity and are counting on floating PV as a real pillar in their plan to decarbonize the power sector.

While some installations exist in Europe – mostly in the Netherlands, France and the UK – the majority of the floating PV projects are located in Eastern Asia. With less than 600 MW installed in 2017, the market grew and more than 3 GW are now installed. Mountainous countries such as Japan and South Korea are looking seriously in floating PV as a solution for their land-scarcity issue which limit the ground-mounted utility-scale deployment. South Korea opened its largest plant in 2021 with a capacity of 41 MW and is planning to install 2.1 GW of floating PV by 2030. Mountainous countries with limited access to the sea can also benefits from floating PV; Switzerland turned on an installation in a high-altitude reservoir. The high-altitude conditions increase the irradiation levels and increase in turn the actual production of solar panels.

The city-state of Singapore, also affected by land-scarcity, opened a 60 MW floating plant in 2021 on its main water reservoir. Indonesia is also active in the segment and is currently building a 145 MW system on the Cirata Reservoir in West Java. The country has also signed a memorandum of understanding for the development of a 2.2 GW floating solar park. If built, this will be as large as the largest solar power plant currently on land, a 2.2 GW plant located in Qinghai, China. The current largest floating PV also belongs to China, with 320 MW located in Dezhou. A major advantage of floating PV is the possibility to combine it with existing hydropower dam.

Fig 33. Floating PV annual and total isntallation capacity



Source: IEA-PVPS (2021)

3.3.3. Agri-PV

The combination of agriculture and photovoltaics ("Agri-PV" or "agrivoltaics") offers an innovative and cost-effective solution to simultaneously promote the clean energy transition and sustainable agriculture. Various designs are shown in the technology reports. Its main and powerful feature is to reduce land competition between solar and agriculture while guaranteeing the efficiency and viability of both activities. Since 2014, around 2,800 Agri-PV systems have been deployed worldwide, and the total capacity reached 2.9 GW at the end of 2020. The sector has seen significant growth in Japan, South Korea, and China, where regulatory frameworks and

support schemes have already been in place for a number of years. China is also home of the largest agri-PV project, with a capacity of 1 GW in the Ningxia Province. Other countries such as Chile, the Gambia, and Mali are equipped with major installations. In Europe, the sector's growth is mainly concentrated in France, Greece, the Netherlands and Spain. The sector can also expect a sharp growth in Italy as well, which dedicated 1.1 billion EUR of its post-Covid recovery plan to install 2 GW of agrivoltaics. In addition, the Italian Ministry of Ecological Transition created guidelines that PV plant owners must consider for their plant to be considered agrivoltaics.

3.3.4. Off-grid solar

3.3.4.1. Off-grid solar PV technologies

The UN Sustainable Development goal aims to achieve access to affordable, reliable, sustainable, and modern energy by 2030 for everyone. In 2021, there is still an estimated 759 million people worldwide with no access to electricity and around 1 billion people who only access an unreliable grid. Off-grid solar represents a solution for millions of people across the globe and will be key to achieve universal energy access.

The off-grid solar sector covers many applications:

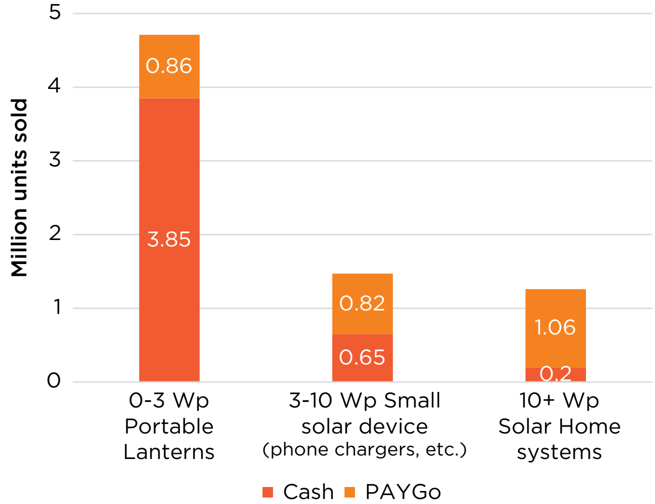
- Lightning products: This is mostly about solar lanterns, which can be used in remote areas without access to electricity grids. As simple as it seems, having lights in poorer areas can help development and general equality (increase sentiment of security for women, improves education and literacy by allowing children to study after dark, improve lung health by replacing kerosene-based lightning sources). The different systems' size usually just varies in how many lights can be turned on and if there is a possibility to charge a mobile phone simultaneously.
- Solar home systems (SHS), as the name suggest, powers a house with photovoltaic power in rural areas disconnected from the grid. They have become increasingly important in several countries to achieve their electrification goal as it comes as a cheaper solution than extending the grid, while being effective to cover the basic electricity needs of a household (fridge, radio, communication, television, etc.). While SHS' capacity typically starts around 10 W, technology's improvement and reduction in solar PV cost allow to observe SHS of up +100 W.

Global off-grid solar PV increased from 7.7 GW in 2020 to 9.0 GW in 2021.

Two types of business models rule the off-grid solar PV:

- Cash sales: the traditional business model for off-grid solar is a cash upfront payment. As the system capacity remains relatively low, this remains the predominant business model.
- PAYGo: This is a newer financial mechanism in which companies offer credit to the consumer to purchase a larger system that is then reimbursed in regular settlement. It is the PAYGo system that really allowed the development of larger installations: in 2021, more than 80% of SHS were purchased under this mechanism. On the contrary, more than 80% of portable lanterns under 3 Wp were paid in cash. For systems ranging from 3-10 W, the share is more balancing with 45% in cash and 55% in PAYGo (see Fig 34).

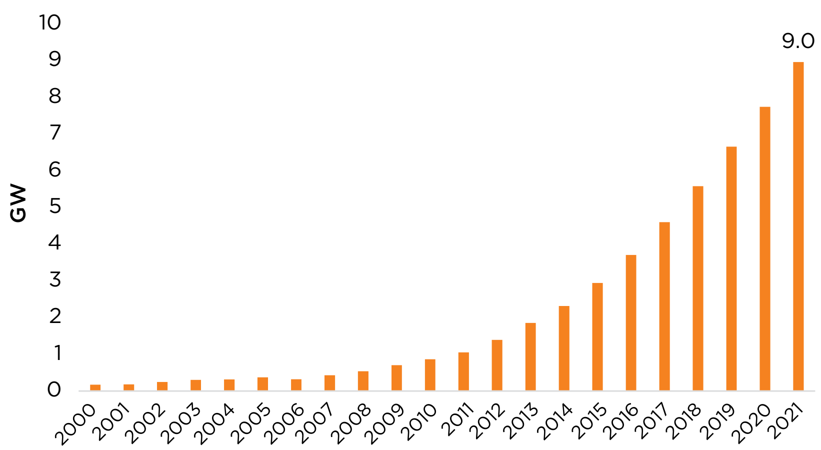
Fig 34. Volume of off-grid solar products sold, by size and type of sale, 2021



Source: GOGLA

Tracking the development made by the off-grid solar sector is difficult because it relies a lot on the private sector and on remote, small, and sometimes informal providers. This is why turning to the supply side and GOGLA's database for the number of units sold is often necessary. Nevertheless, at the end of 2021, it is estimated that the cumulative off-grid solar PV installation stood at 9 GW and experienced a growth rate of 16% in both 2020 and 2021. Those are the lowest growth rate of the past decade when the total off-grid solar grew on average by 26% in the period 2011-2019 (see Fig. 35).

Fig 35. Cumulative off-grid solar PV capacity 2000-2021

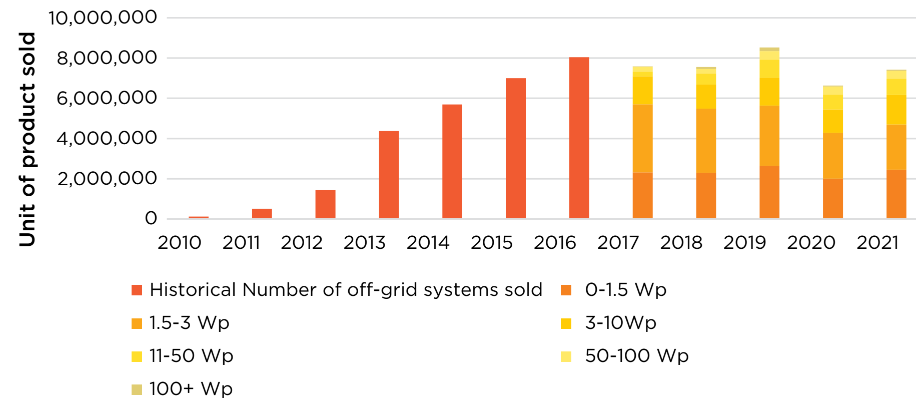


Source: IEA, IRENA, IHS

This highlights the impact of COVID-19 on the global sales of lighting products, even if they were already stagnating since 2016 (see Fig. 36 from GOGLA). The market experienced an annual 22% decrease in 2020 with almost 2 million less units sold compared to the previous year which set the record at 8.5 million units sold. If some segment of the off-grid market is on the recovery path and sales volume increased by 12% in 2021 to reach 7.4 million units, most economic prospects tend to show that lower-income economies' growth is more fragile than for more advanced economies. Indeed, many purchasers of off-grid solar systems are active in the informal sector with unstable employment conditions which was more severely impacted by the restriction imposed to limit the spread of the COVID-19. As a result, the long-term financial situation of buyers is harmed and their ability to afford larger solar systems is diminished. This is visible on Fig. 37 which shows the sales of different solar products between 2019 and 2021. While almost all products below 20 Wp saw the beginning of a recovery in 2021 compared to 2020 level, SHS sales above 20 W are still affected and remains below 2020 levels, depicting the lower resilience of this segment.

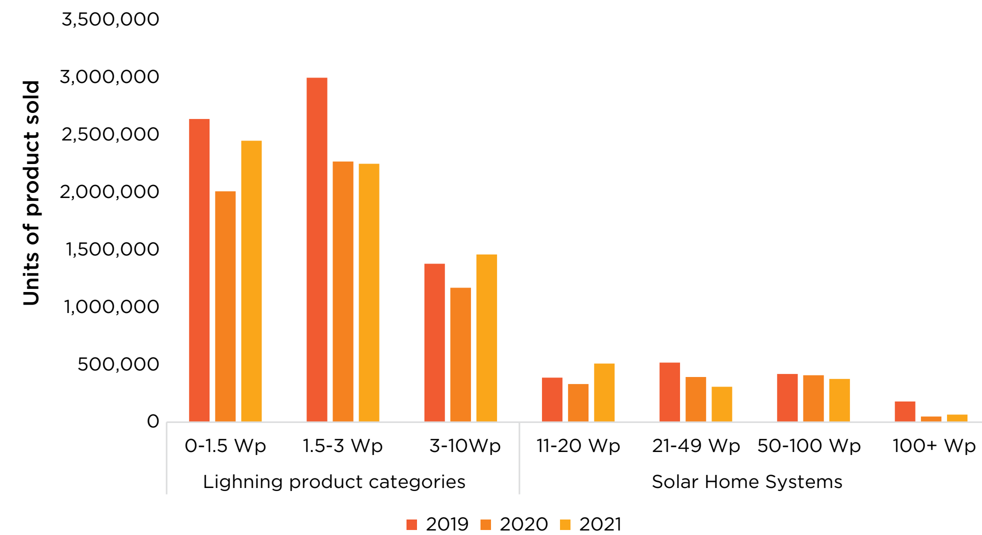
Annual sales of off-grid solar products remain flat since 2016, and sales of systems above 20 Wp are struggling to recover from the covid-19 crisis.

Fig 36. Global annual sales of lighting products



Source: GOGLA

Fig 37. Global annual sales of solar lantherns & Solar Home Systems



Source: GOGLA

Table 6: Overview of technologies and case studies

Product and technologies	Definition	Small infographic/ picture of the technology
Solar lanterns	A simple application of photovoltaic technology with power ranges from 0 to 3 W which can power a single light, and a mobile charging station, for the upper power range system.	
Multi-light systems	A larger system from 3W to 10 W which can power multiple lights as well as one mobile charging station. This can provide light for a single person and up to a full household.	
Solar Home Systems	Ranging from 11W to 100W+ systems, those can cover different usages. Systems up to 20W are used to power several lights, mobiles power stations and a radio. As the capacity grows, systems can include a television, fans or refrigerators	
Solar Water Pump	A water pump powered by solar energy for household living to far from regular water pipe supply.	

3.3.4.2. Mini grids

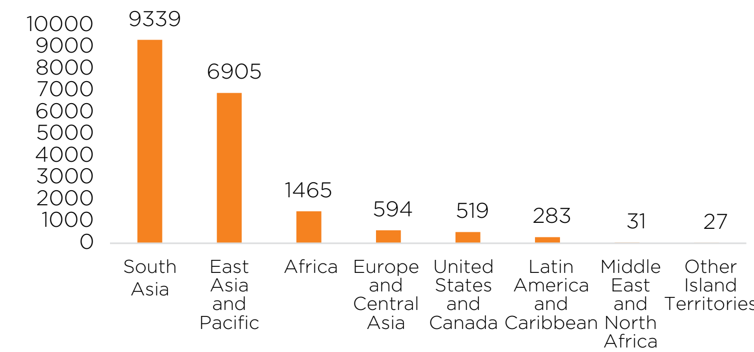
The World Bank defines a mini grid as an "electric power generation and distribution system that provides electricity to just a few customers in a remote settlement or bring power to hundreds of thousands of customers in a town or city. They can be fully isolated from the main grid or connected to it but able to intentionally isolate ("island") themselves from the grid."[2] Two things come out of this definition. First, the main feature of a mini grid is its ability to operate autonomously in remote areas and, second, it is most optimal in areas with a somewhat important population density. Indeed, mini grids are the most economical option to power areas which are too far away from the main grid, as expending it will be too expensive, but have a sufficient power demand to justify the installation cost of a mini grid versus several solar home systems.

Mini grids are not a recent technology and are nowadays deployed globally in countries to increase electrification rates. The World Bank estimates that, in 2019, around 47 million people were connected to one of the 19,000 mini grids deployed, most of them in Asia and Pacific (see Fig. 38 and 39 from World Bank). In order to reach universal energy access in 2030, those numbers must increase to 490 million people and at least 210,000 mini grids.

The first generation of mini grid was installed in the late 19th and early 20th century and helped industrialization of most modern economies. With time, they eventually got bigger and connected to each other to create the grid we know today. A second generation of mini grids started in the 1980s in isolated rural areas powered by diesel or hydro to provide electricity to local communities. They went on until the early 2000 and draw many lessons on the technical and financial viability of mini grids, as well as on policy regulations. Then came the third generation of mini grids which is predominant today. They are usually powered by solar PV or hybrid solution (PV+diesel) and are run by private companies (see Fig. 40 from Bloomberg). Third generation installations become more complex and can be connected to the grid in order to prevent any outage. They usually incorporate storage capacity, remote management systems, smart meters, etc. Instead of running one-off project, companies are now building complete portfolio of mini grids and develop diverse business models, one of the most common being the utility operator model. A utility company typically owns and operates the mini-grid and charges the supply of electricity to the various customers. Mini grids can also be owned by a public entity but operated by a private company, which work then together under a partnership. The degree of ownership can of course change between projects, the presence of the public entities is sometimes limited to provide subsidies and incentives for the construction of the mini-grid.

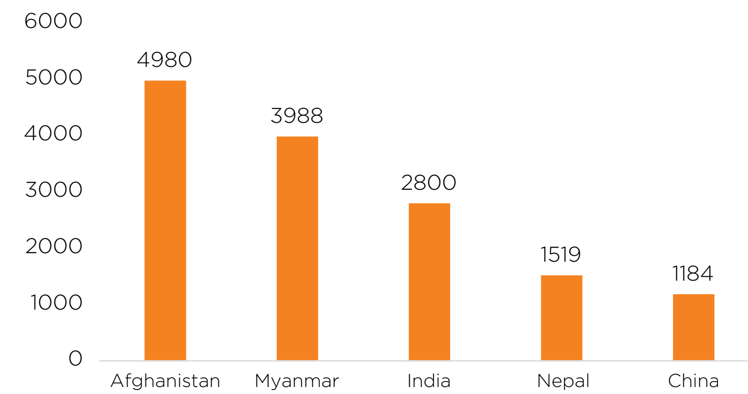
[2] World Bank, Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers, 2019.

Fig 38. Total number of installed mini grids in 2019



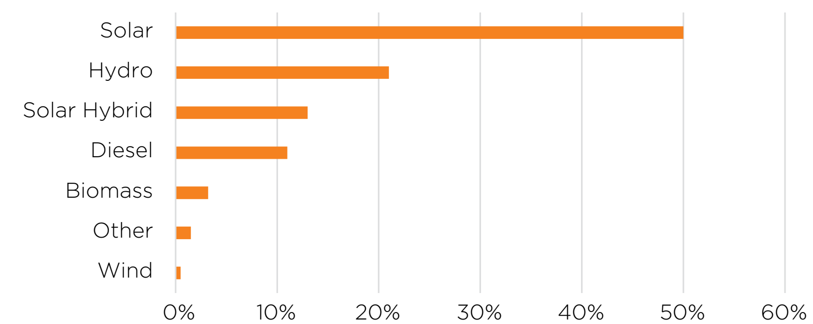
Source: World Bank 2019

Fig 39. Top 5 countries in mini-grids total installation in 2019



Source: World Bank 2019

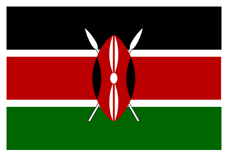
Fig 40. Percentage of installed mini-grid by technology in 2020



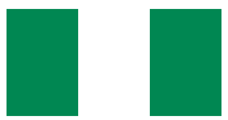
Source: Bloomberg, Sustainable Energy for All (Mini-Grids Partnership)

3.3.4.3. Off-grid development and policy

Most off-grid installations are founded in Asia-Pacific and in Sub-Saharan Africa (SSA). With the lowest rate of electrification in the world, SSA finds in off-grid solar a means to overcome the lack of grid availability and to answer some of the rural population's basic needs. SSA countries can rely on different options to increase their access to electricity but geographic characteristics can impact their choices. Grid-extension is easier for smaller countries such as Rwanda, Burundi or Uganda while larger countries such as Angola, Democratic Republic of Congo or Niger will rely more on SHS systems and mini-grids. In Asia Pacific, the market is more developed, and off-grid mostly serves as a grid extension. For islands in the Pacific, which are very dependent on expensive fossil fuel imports, off grid solar allow to reduce their import expenses and turn to greener solution at the same time. The tracking of SDG7 clearly shows that off grid and midi grid are an immense pillar of a comprehensive approach to increase access for energy. The following paragraphs present some insights on countries with relevant off grid developments.

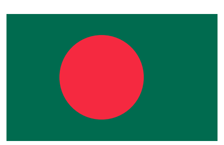


Kenya's government support for renewable and off grid has turned the country into one of the most established markets in SSA. Through several policies, the government has simplified the access to financing opportunities and removed legislative barriers for self-consumption, boosting the installation of solar home systems. Kenya is also a pioneer in the development of mini-grid projects. It first started to allow small projects to be run with minimal oversight, and it eventually turned into larger programmes such as the Kenya Off-Grid Solar Project, aiming at empowering the least developed part of the country.

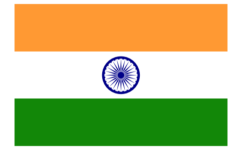


Nigeria's growing market for solar off-grid is poised to continue thanks to the Nigeria Renewable Energy Master Plan aiming to deploy 4 million of solar home systems by 2025. In addition, Sustainable Energy for All (SE4ALL) foresees at least 8 GW through a mix of mini grids and solar home systems. This would represent about 20% of the total generation capacity of the country. A clear framework for mini grid has also been put in place which helps developer to have good visibility on the economic viability of projects. Nigeria also dedicated different funds to support development of mini grids.

Senegal's investments in the off grid solar sector started in the 1990's when the government put together a framework for private development of SHS. Since then, the sector attracted a lot of investment and grew quickly, with both cash and, more recently, PAYGo scheme. As several other countries, solar off grid companies were categorised as an essential service and were exempted from the national restrictions imposed to limit the spread of COVID-19.



Electrification gains in **Bangladesh** were among the fastest in the world during the 2010s', starting at 55% in 2010 to reach 96% in 2020. This development was partly backed by a SHS program implemented in 2003 and targeting rural areas. The program ended in 2018 and the country installed over 4 million systems and helped to bring access to 20 million people during this time span. In total, the program generated more than USD 1,000 million in investment from international development partners under loans.



India also supports the development of solar off grid with different programs. The main one being the Off-Grid and Decentralised PV Program, launched in 2017 by the Ministry of New and Renewable Energy, which aims at installing 2 GW of SHS, solar streetlight, solar pump, and solar lanterns in areas that the grid cannot reach. In the same light, the Atal Jyoti Yojana (YJAY) program was launched in 2016 to finance over 3 million solar streetlights across the country.

3.4. Solar Thermal

3.4.1. Solar Thermal Electricity/ Concentrated Solar Power

The market for concentrated solar power (CSP) has not been very hot lately. In fact, the global installed capacity decreased for the first time ever: the market stood slightly above 6.5 GW in 2020 and decreased to 6.4 GW in 2021. The drop comes from the decommissioning of the Californian Solar Energy Generation Systems (SEGS) which turned off five of its nine solar thermal plants in July 2021. The total system's capacity used to be 365 MW made up of nine solar thermal plants, two of which were already replaced by solar PV in 2015. The system which started operation in the 1980's was the world's oldest solar thermal power installation.

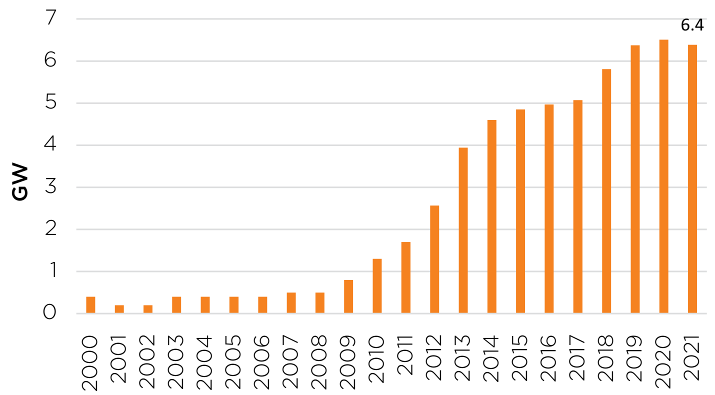
The only country which plugged new CSP capacity in 2021 is Chile with the grid-connection of the 110 MW Cerro Dominador project in the Atacama desert. The project is part of a 210 MW hybrid system combining CSP and solar PV.

Global CSP installation decreased from 6.5 GW in 2020 to 6.4 GW in 2021, following the decommissioning a large plant in the United-States. This is the first solar technology in history to experience a decrease in cumulative installation level.

On overall, the market for CSP is stagnating since 2015 when Spain and the United States, the two major countries in the sectors with total fleet of 2.3 GW and 1.7 GW respectively, stopped adding new capacity. The reasons come mostly from a strong competition from solar PV and a lack of policies.

However, the year 2022 could be pivotal for the market. Indeed, China and the United Arab Emirates (UAE) are moving forward with the construction of large installations that are expected to come online this year. China has around 250 MW of projects under development and the 50 MW Yumen Xinneng should come online in the second half of 2022. According to the country's 14th Five-Year Plan, solar thermal technologies will also receive support from the government and several plans should come online by 2024. In the UAE, it's all about the big projects. One of the largest, the Mohammed bin Rashid Al Maktoum Solar Park is under construction and aimed to reach a total capacity of 5 GW of solar PV and CSP combined. The fourth phase of the project's construction includes a 100 MW concentrated solar tower and a 600 MW parabolic basin complex. The CSP tower was inaugurated in August 2021, as well as the first 200 MW of the parabolic basin complex, whose remaining capacity is expected to come online in 2022. Elsewhere on the globe, Morocco, Zambia, South Africa and Australia are amongst the countries with the most projects under development.

Fig 41. Total CSP installation



Source: IRENA, IEA

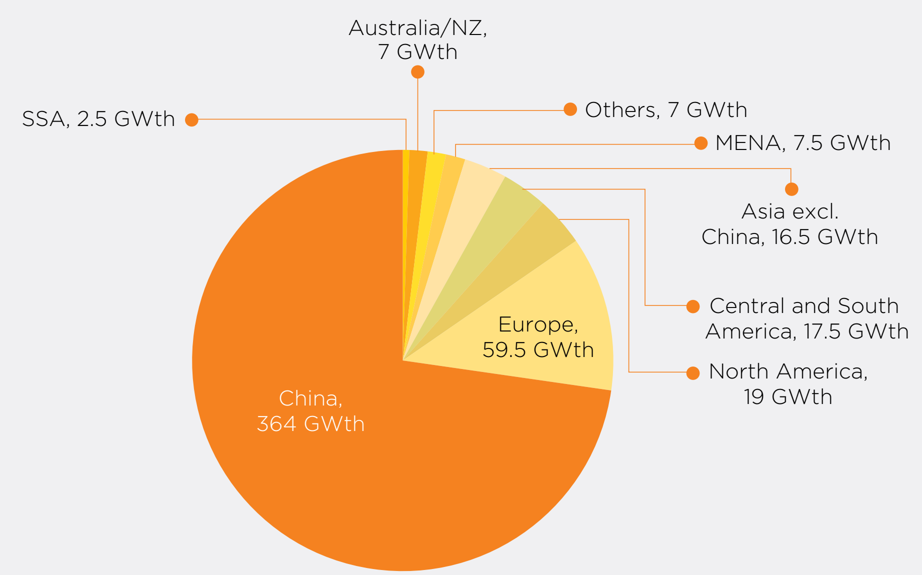
3.4.2. Solar Thermal Heating

The Solar Heating & Cooling Programme from the IEA (IEA-SHC) estimates that the worldwide solar thermal heating market reached 522 GWth at the end of 2021, representing a 3% growth from 2020 and a net increase of 21 GWth. In terms of generation, the total fleet energy yielded 425 TWh in 2021.

As for most existing renewable technologies, China is leading the way in terms of absolute installation numbers. Regarding solar thermal heating, the country possesses 73% of the total installed capacity (364 GWth) and accounted for 83% of the 21 GWth newly installed in 2021 (18 GWth). This dominance is not recent, as the country already had 69% of all installed collectors back in 2006. Following in second position is Europe and its 59 GWth, six times less than China. Together, the two regions represent almost 85% of the global fleet. The other continents are sharing the remaining 15%: North America (3.8%), Central and South America (3.5%), Asia (3.3%), MENA (1.5%), Australia and New Zealand (1.4%), SSA (0.5%), others (1.5%).

CAGR of solar thermal heating is 4% between 2019 and 2021. This is lower than the 6% CAGR for the 2011-2021 period.

Fig 42. Share of total solar thermal installed capacity by region in 2020



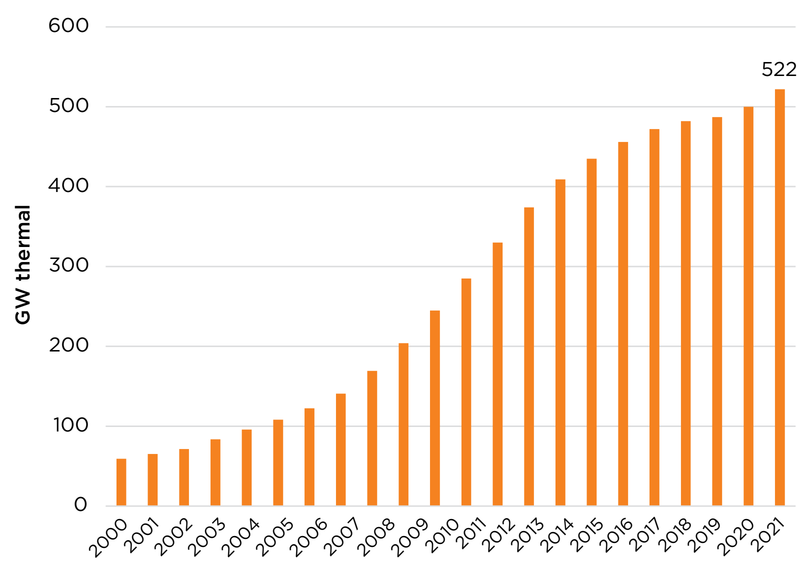
Source: IEA Solar Heating & Cooling Programme, 2022

The solar heating market is segmented into three main applications:

- **Large-scale solar heating systems for district or building heating.**
  - » The first application of large-scale solar heating is **Solar district heating (SDH)**. SDH are large systems integrated into the local district heating network. Basically, a centralized solar heat farm uses solar panels to heat up water, which then flows to houses, buildings or factories to warm them. During warmer period of the year, SDH can fully replace fossil-based heating solutions and, thanks to the development of thermal storage, it is also possible to store the heat generated in summer for winter.

    There is about 300 SDH systems (1.6 GWth) across the global and northern European countries are leading the way, with Denmark being number one totaling 125 system. However, the Danish market was struggling in 2020 and 2021 due to changes in policies and funding conditions and only 4 systems were installed during those two years. Other countries to note are Germany (45 systems), China (41), Sweden (24), Austria (22), Poland and France (8 each).
  - » The second large-scale **solar heating application is for residential, public, and commercial sector** (above 350 kWth). The usage is similar than for SDH, but in smaller version for hospitals, hotels, etc. The world counts 230 systems with a total capacity of 324 MWth. China is leading this segment with 223 MWth.
- **Solar heat for industrial processes (SHIP):** Heating is an important part of many industrial processes which opens an opportunity for solar heating systems of various size.
- **Photovoltaic Thermal Systems (PVT):** Also called hybrid solar collectors, those systems combine solar PV and solar thermal collector in order to produce both electricity and heat. The thermal collector benefits from the wasted heat of the solar PV to warm a fluid which is then used for heating purpose afterward. Combining the two technologies in one system allows for higher efficiency than using them independently. It is still a quite specialized market of about 751 MWth, 250 MWpeak mostly established in Europe and Asia-excluding-China. Still, according to IEA-SHC the global market grew by an average of 9% between 2017 and 2020, and by 13% in 2021. The European market alone grew by 21% in 2021, a net increase of 79.9 MWth and 27.6 MWpeak.

Fig 43. Global solar thermal capacity 2000-2021



Source: IEA Solar Heating & Cooling Programme, REN21

3.5. PV and VRES penetration in the electricity mix

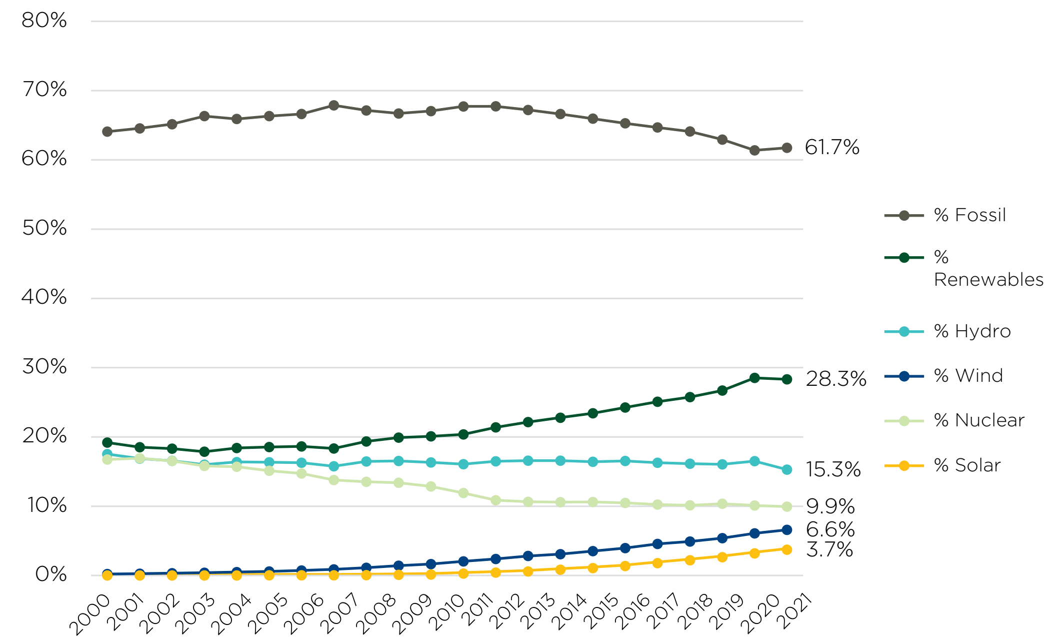
3.5.1. PV penetration in the grid

Even though the solar sector experienced strong development in the last two decades, its position in the global power generation sector remains humble as it generated a mere 3.7% of the global electricity in 2021 (see fig 44). This is 0.5% higher than in 2020, and 1.1% higher than in 2019. By contrast, fossil fuels provided 61.7% of the global electricity, hydro 15.3%, nuclear 9.9%, and wind 6.6%.

Solar PV generated 3.7% of the global electricity in 2021. This is 0.5% higher than in 2020.

The share of renewable in electricity generation decreased from 29% in 2020 to 28.3% in 2021. The decrease is largely attributed to a reduction of hydroelectricity and a surge in coal, used to answer to the economy's post covid-19 recovery.

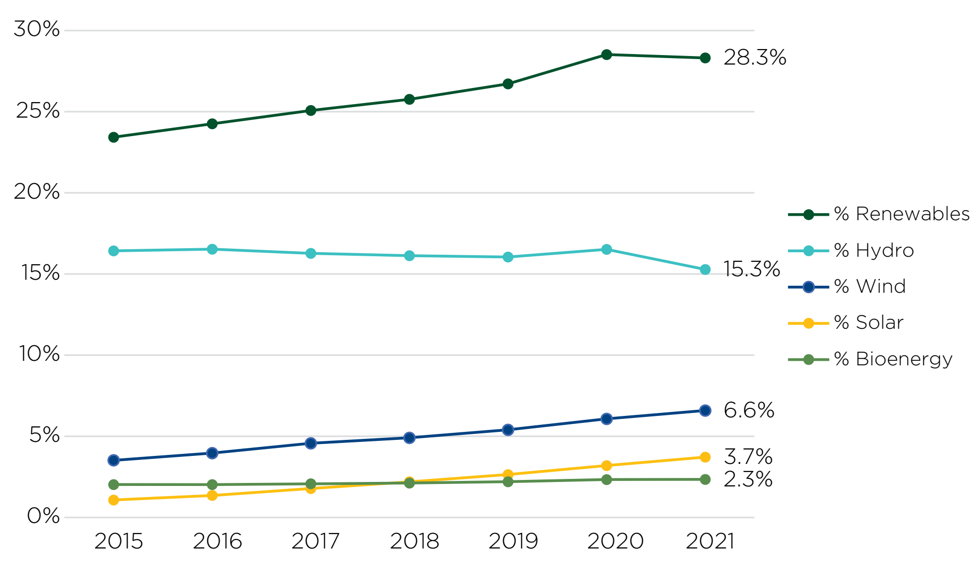
Fig 44. Share of global electricity generation by source, 2000-2021



Source: Ember

Despite solar's growth, in 2021 the overall share of renewables in electricity mix marginally decreased to 28.3% (a breakdown of the technologies contributing to total renewable electricity is provided in Fig. 45). This is due to two concomitant factors. The first factor is that the largest renewable source, hydro, suffered from the severe droughts in Latin America and Asia. The increase by 1% in wind and solar generation was not enough to counterbalance the 1.2% absolute decrease of hydroelectric generation.

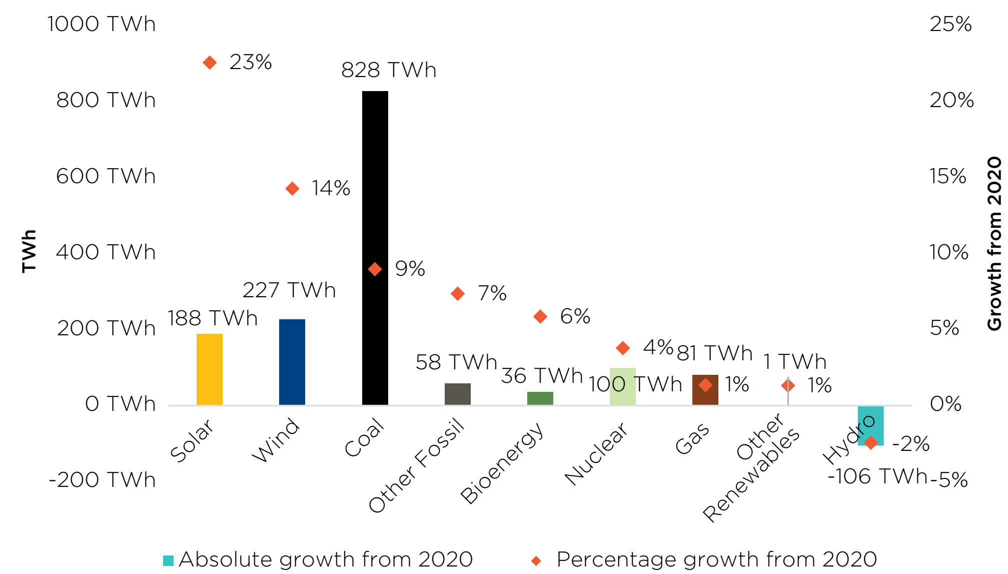
Fig 45. Share of renewable electricity generation by technology, 2015-2021



Source: Ember

The second factor contributing to the decrease in the RES share is that countries turned back on several fossil fuel-based power plants to meet the rising power demand resulting from the post-COVID-19 recovery (see Fig. 46). In 2021, global electricity demand rose by 1,414 TWh, and most of this new demand was fueled by coal. Despite solar and wind electricity generation increased by 23% and 14% compared to the previous year, they met only 29% of the new electricity demand. By contrast, coal-fired electricity grew by 9% from 2020, providing 59% of the additional power demand.

Fig 46. Power technologies used to meet global additional electricity demand in 2021

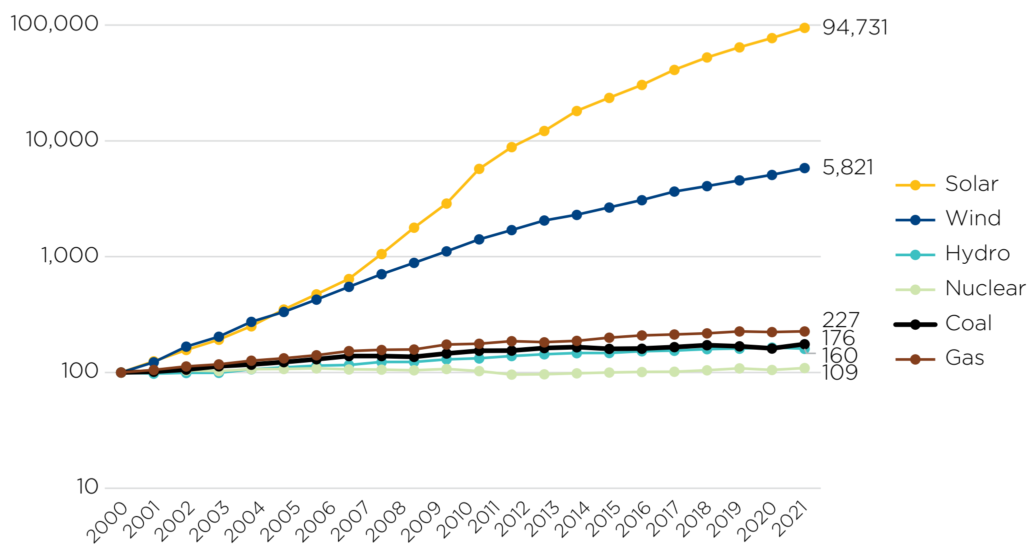


Source: Ember

Solar PV generation grew 23% from 2020 to 2021. Wind increased by 14% while hydro decrease by 2%.

Although the contribution of wind and solar to the global electricity mix may still appear small, the growth of variable renewable technologies is progressing at unprecedented pace. In the last 20 years, solar electricity has increased over 900 times, while wind's contribution has increased 58 times (see Fig. 47). In the same time span, conventional technologies like coal, gas, nuclear and hydro have remained overall stable. Solar PV has been the fastest growing power generation technology in the last 17 years.

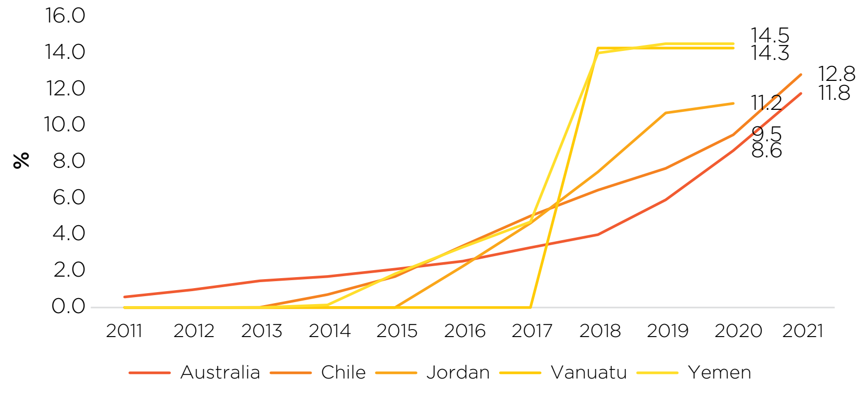
Fig 47. Growth in TWh per technology. Year 2000 = 100



Source: Ember

Solar PV has been the fastest growing power generation technology for the last 16 years

Fig 48. Top 5 countries of share of solar PV in electricity mix

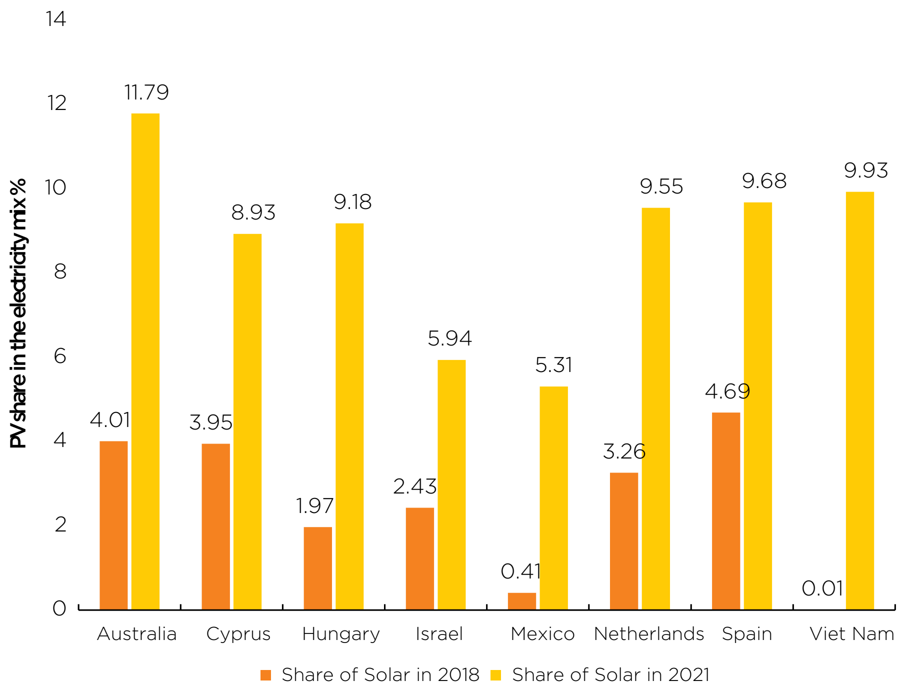


The top 5 countries in terms of solar PV in the electricity mix are displayed in the Fig. 48. The data are from 2021, or 2020 when not available. Australia, Chile and Jordan experienced a smooth year-on-year growth that reflect the solar PV development in both countries. Jordan remains quite specific as it includes wheeling scheme to overcome their limited grid-capacity. On the other end, Vanuatu and Yemen solar PV deployments were quite fulgurant. While Vanuatu general electricity demand is very small, several solar PV installations that replaced diesel generator in 2018 have immediately increased the share of solar PV in the electricity mix. The story of Yemen is rather different. The war has decimated the country's national grid, leaving only few people connected. Many farmers, hospitals and schools were therefore relying on diesel generators for their power need. However, during the period 2010-2016, the price of diesel almost tripled in Yemen and many institutions turned to solar PV and solar home systems to generate their electricity, which they offered thanks to micro-credit programs and support from international financial institutions.

Several countries are also demonstrating the speed at which solar PV can be deployed. Within 3 years only, Australia, Cyprus, Hungary, Israel, Mexico, Netherlands, Spain and Vietnam have all more than double their share of solar PV in their national electricity mix (Fig. 49). This list includes only countries with a PV share higher than 5% in 2021; several other countries across the globe are growing rapidly the share of PV in their electricity mix. While the share of solar PV in the Hungarian electricity mix also showed a beautiful improvement, about 25% of the national electricity demand is covered by imports. The share of Hungarian domestic solar PV production in the total electricity demand stands at around 6%.

The share of Hungarian domestic solar PV production in the total electricity demand stands at around 6%.

Fig 49. Countries that at least double their share of PV in the electricity mix between 2018-2021



Source: Ember

Two outstanding examples are Vietnam and Australia. Started from basically zero solar in 2018, Vietnam became the 3rd largest solar installer and the 10th solar electricity generator in less than two years. The growth of PV capacity was so fast that it allowed the country to significantly reduce the use of fossil fuel, even in a context of a growing electricity demand. Once again, the reason behind this is the policies which were put in place: the Vietnamese government offered companies a very attractive 20-year contract to buy electricity from new solar and wind installations at a fixed rate, which drove installations to skyrocketing levels, especially for solar. The goal of the government was to fast-track renewable deployment to avoid any electricity shortage as the delivery of several coal and gas power plants was late. This worked even too well: the national grid was unable to keep up with the pace of development of solar and wind and Vietnam's National Load Dispatch Center (NLDC) announced that it will not allow any new solar and wind capacities in 2022. Because of the grid congestion, many projects have to face regular and severe curtailments. Furthermore, the government eventually had to cap the installations eligible for the FIT.

The Vietnamese case can draw two lessons for solar PV development. First, stop-and-go policies must be avoided at all costs as the market keeps bouncing and create uncertainties for investors. In the worst case scenario, investors lose confidence in the market to stabilize and grow in the long term. They will eventually stop financing new projects, with disastrous repercussions on the market. Second, the development of renewables should come together with a plan to develop the grid and the necessary infrastructure to integrate the new power capacities and avoid curtailment, which limit the benefits of power companies and hence their interest in the market.

The Australian case shows a very different picture. Australia achieved to sustain a slower but smoother development through regular and stable supporting policies, as already described above. These policies allowed the country to increase its solar PV share from 5.9% in 2019 to 10.9% in 2021. Today, around one house out of three is equipped with solar PV in the country, and the positive attitude towards renewables from the new government let one think that the growth will continue.

The top 5 market of each continent in share of solar in the electricity mix is depicted in Fig. 50 to Fig. 53.

4.2% of electricity in APAC came from solar PV in 2021. Europe follows with 3.8% (EU27, 5.6%). AMER is at 3.4%. Middle East and Africa stand respectively at 1.7% and 1.2%.

Fig 50. Europe top 5 market in PV in the electricity mix

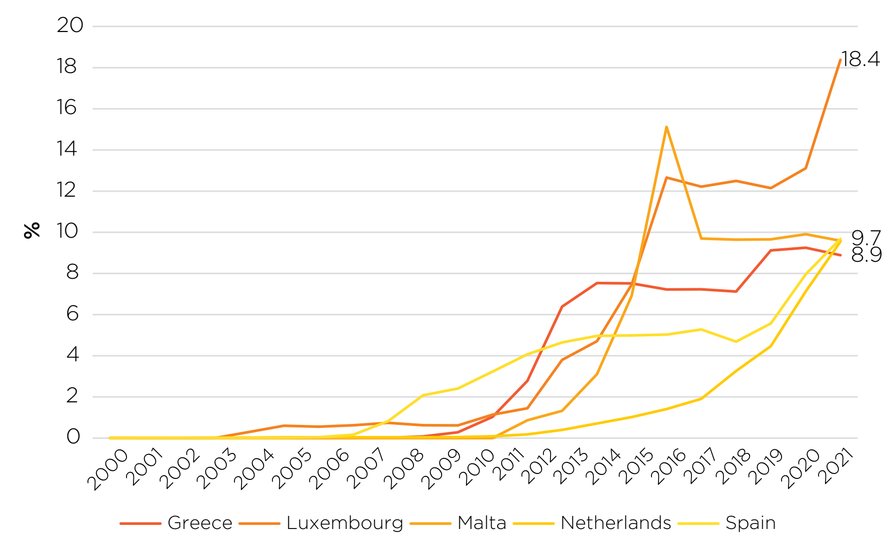


Fig 51. APAC top 5 market in PV in the electricity mix

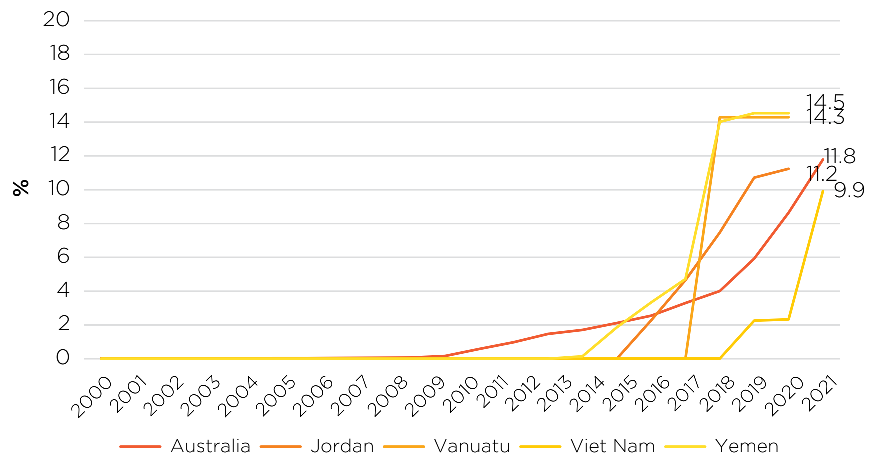


Fig 52. AMER top 5 market in PV in the electricity mix

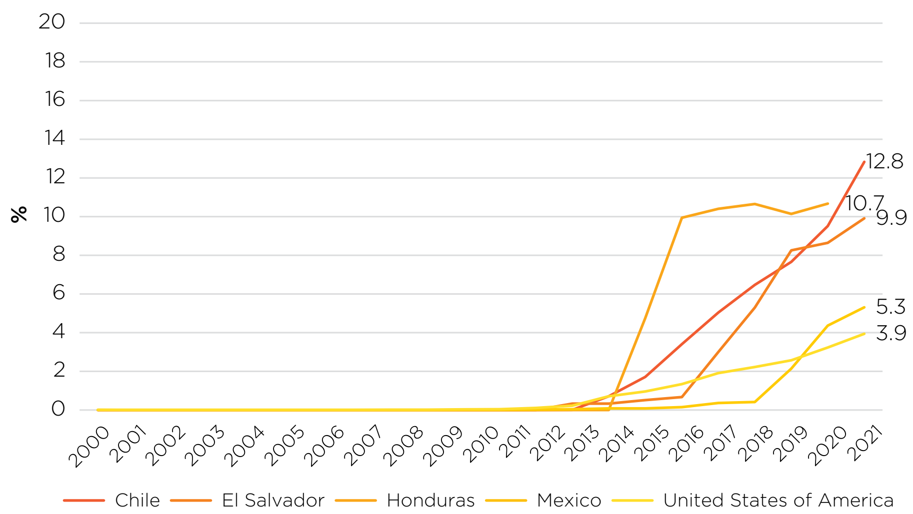
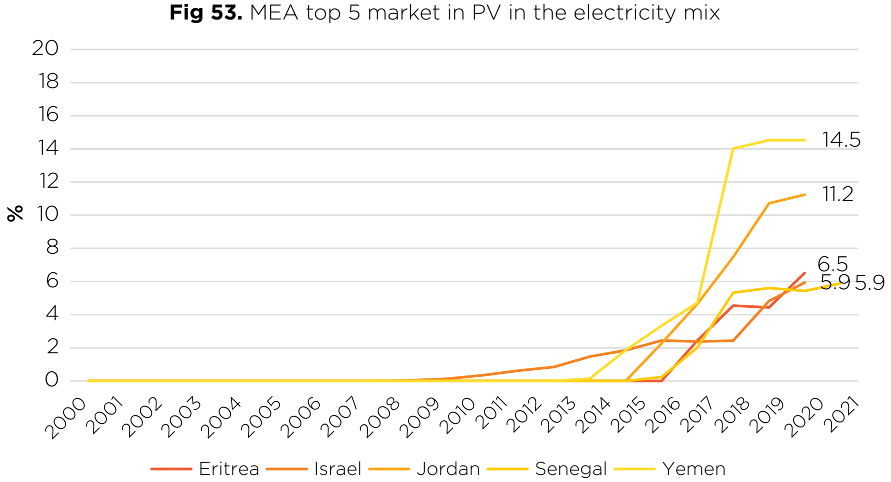


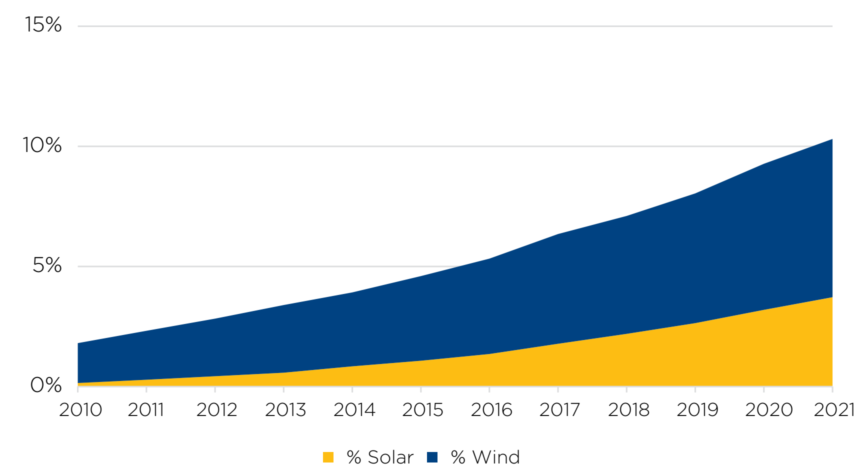
Fig 53. MEA top 5 market in PV in the electricity mix



3.5.2. PV and wind penetration in the grid

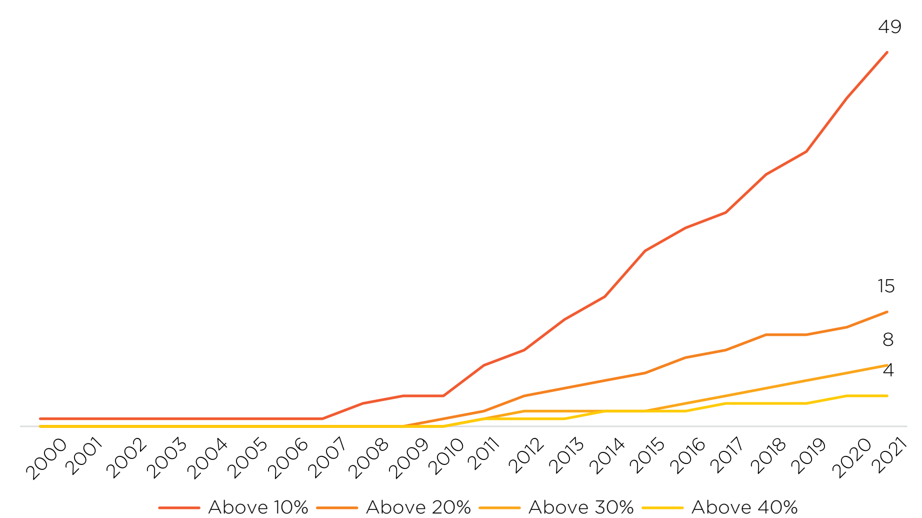
Analyzing the penetration of solar and wind technologies combined provides an insightful overview of the role of variable renewable energy technologies at the global and national level. The two technologies experienced the highest year-on-year growth rate in 2021, respectively 23% and 14%, and accounted for more than 10% of global generation electricity for the first time (Fig. 54).

Fig 54. Share of solar & wind generation in global electricity generation



At the national level, the number of countries with increasingly high shares of wind and solar electricity is growing larger. In 2021, six new countries have reached a 10% share, bringing the total amount of countries to 49 (see Fig. 55). Of this group, 15 countries have more than 20% of electricity coming from wind and solar, 8 are above 30%, and 4 are above 40%.

Fig 55. Number of countries above 10/20/30/40% wind+solar share in the electricity mix

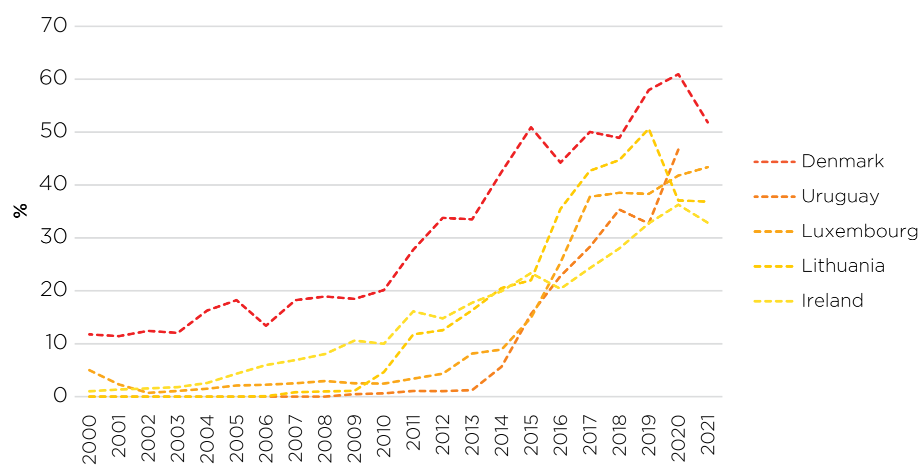


Source: Ember

49 countries reached 10% of electricity generation from wind and solar PV in 2021.

The top 5 countries (Denmark, Uruguay, Luxembourg, Lithuania and Ireland) are flying well above the rest of the world, having all crossed the 20% mark already in 2016, and the 30% mark in 2019 (see Fig. 56). In 2020, Denmark was the first country to pass just above the 60% mark, before reducing to 51% in 2021 as coal made a comeback to answer to the higher electricity demand. Ireland experienced the same story when coal generation share went up from 2% in 2020 to 10% in 2021 – almost the same level as in 2017. Lithuania and Luxembourg are somewhat exceptions because, while the share of renewable is high in their national production, most of the electricity they consume is imported from neighboring countries.

Fig 56. Evolution of the top 5 countries with highest wind + solar share



Source: Ember

In terms of wind & solar shares, comparing the top 5 average with the largest solar markets – China, the US, India, the EU-27 – and the world average, it can be observed that large solar deployment in terms of absolute capacity does not necessarily mean high shares of VRES penetration. China and the US have a share of 11.2% and 13.1% respectively, standing just above the world average of 10.3%. India stands below the world average, at 8%, while the EU-27 is the leading region with 19.1% of its electricity coming from wind and solar. (Fig. 57).

Solar PV in the electricity mix

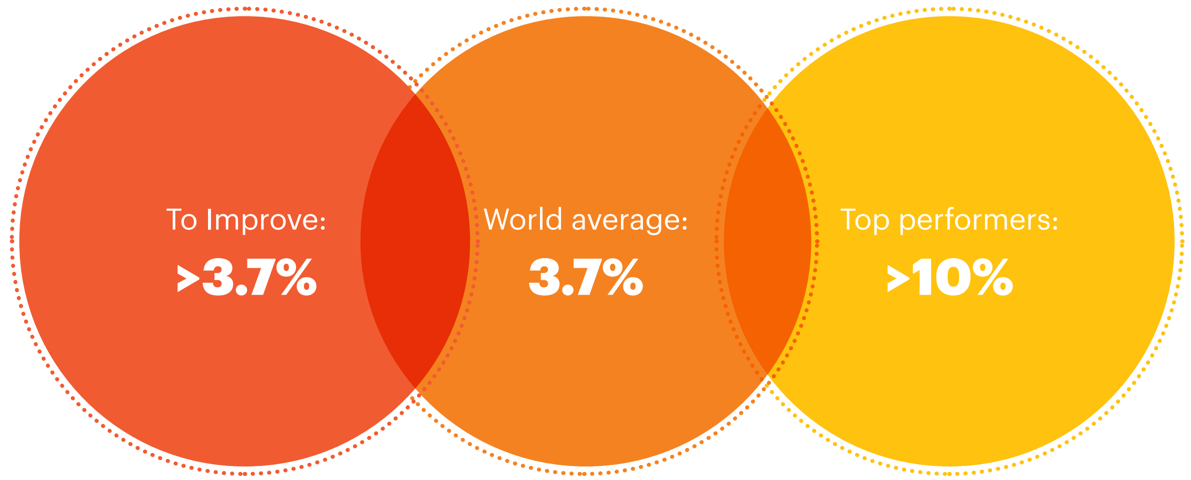
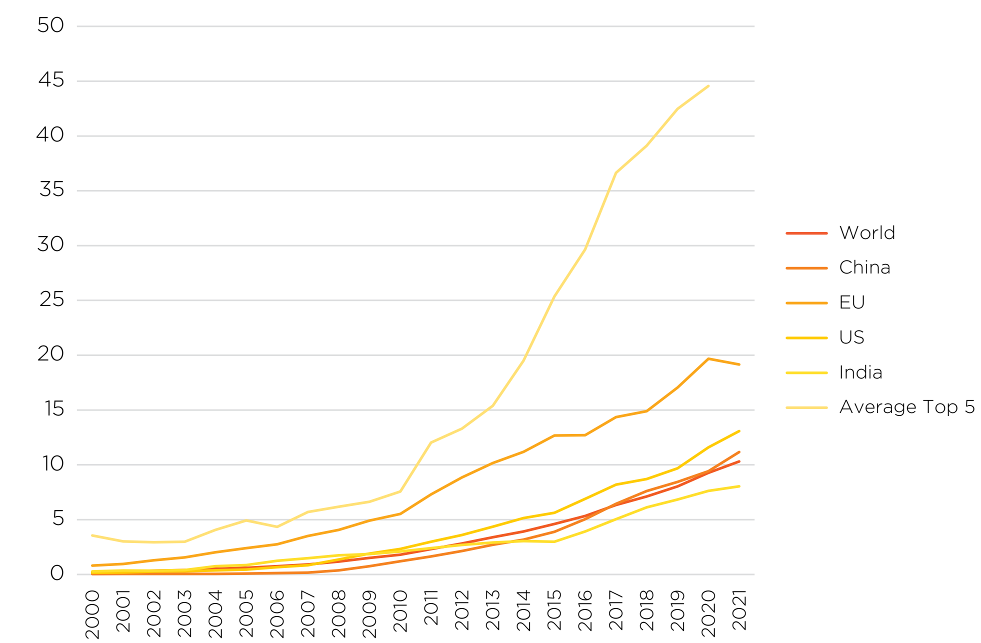


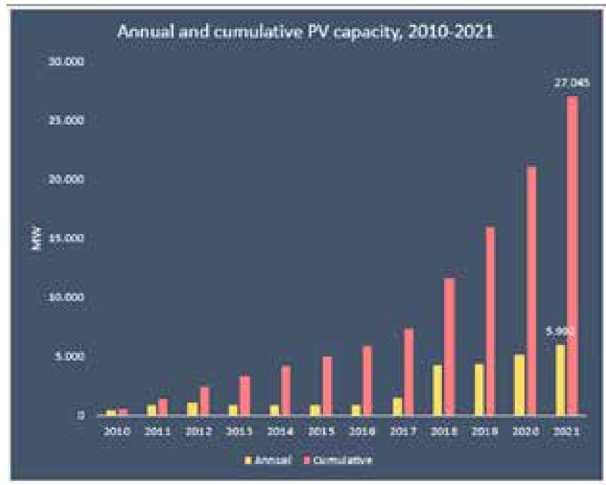
Fig 57. Share of PV and wind - selected countries versus average of top 5

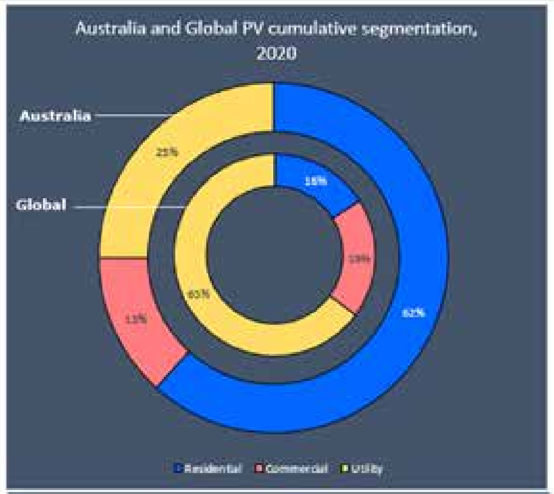


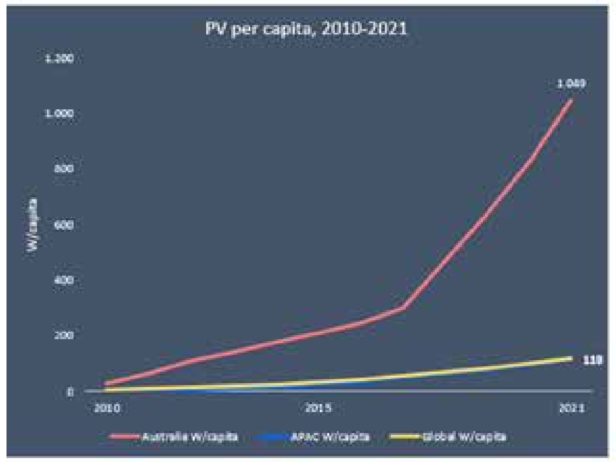
Source: Ember

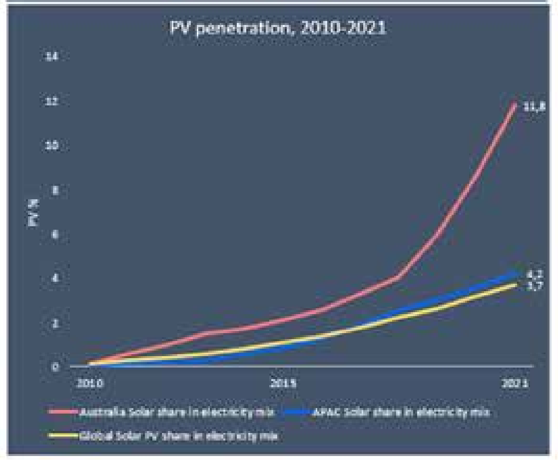
3.6. Solar case studies of selected countries

AUSTRALIA









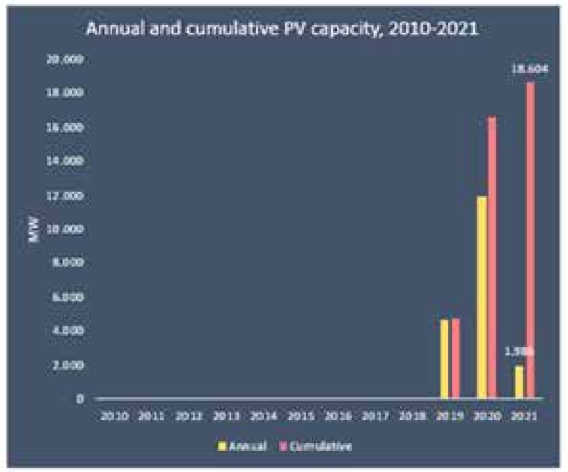
Key drivers to PV deployment

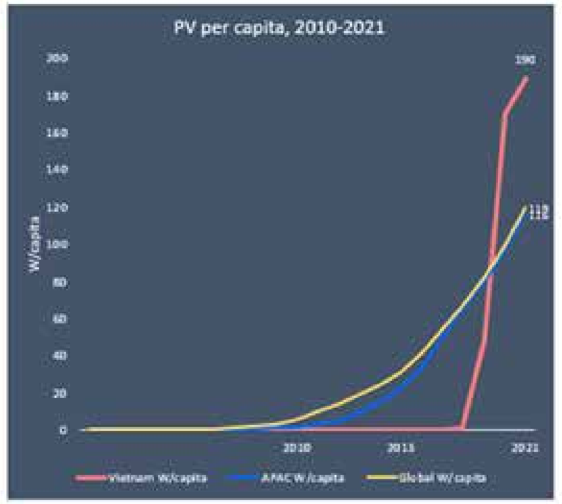
1. The states of New South Wales included the development of five Renewable Energy Zones (REZ) in its Electricity Strategy and Electricity Infrastructure Roadmap. Those REZs aim to assure the production of large amount of clean and affordable electricity, to replace the country's aging fleet of power generation. In August 2022, the Illawarra REZ already attracted 17 GW of clean energy projects, and local authorities expected that each REZ will bring at least 12 GW of clean energy capacity and 2 GW of storage.
2. One of the leading drivers for renewable development in Australia is the Renewable Energy Target scheme, which require electricity retailers to provide a defined percentage of their electricity from renewable sources. This benefits to both large-scale stations and residential installations who can earn certificates for their production of clean electricity, which they can sell to electricity retailers. The retailers then submit the certificates to the Clean Energy Regulator to meet their legal obligation.
3. Feed-in Tariffs are in place to remunerate excess electricity from small-scale solar PV systems installed on a household or a small-business.
4. Several states are offering support for the installation of solar PV. For instance, the Solar Victoria programs offer solar rebate for homeowner and rental properties, as well as interest-free loans, support for storage and energy communities, and others.
5. Even before the start of the global energy crisis, the Australian electricity price has been on the rise due to the unreliability of the coal generation fleet and high network costs. As a result, it has been driving PV self-consumption for residential and small commercial customers.
6. The political support for renewable is as high as ever. The progressist government elected in 2022 vowed to embrace the 2015 Paris Agreement and promised to turn the nation into a hub for renewable energy.
7. One of the best location across the world in terms of solar irradiance and space availability, several energy players are looking at Australia as the future solar-to-hydrogen hub. In 2021, a pipeline of 69 GW of green hydrogen projects was reported – the highest in the world.

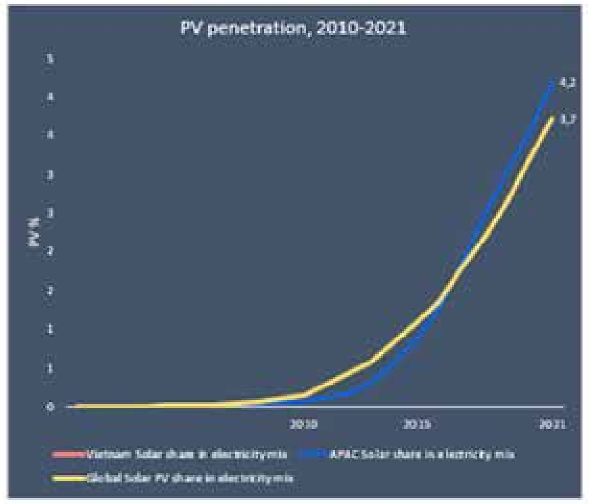
Key barriers to PV deployment:

1. Australia is exiting a long period of anti-renewable policies, the current government has therefore strong momentum to benefit from but need to establish itself as a renewable supporter in the international context.
2. The political relationship with China have been caught in a downward spiral over trade issues and accusations of illicit influence in internal politics, among others. In a worst-case scenario, difficult trade relations could hamper solar PV deployment in Australia as China is the leading provider for solar PV. However, since the 2022 election and the shift in Australian politicians, leaders of both countries seem willing to improve the situation.
3. Solar PV price increase and various global supply chain disruptions could slow down the uptake of renewable in the country. In 2019, the cost of solar installation was still the first reason invoked by homeowners not to have solar panels on their roof.

VIETNAM







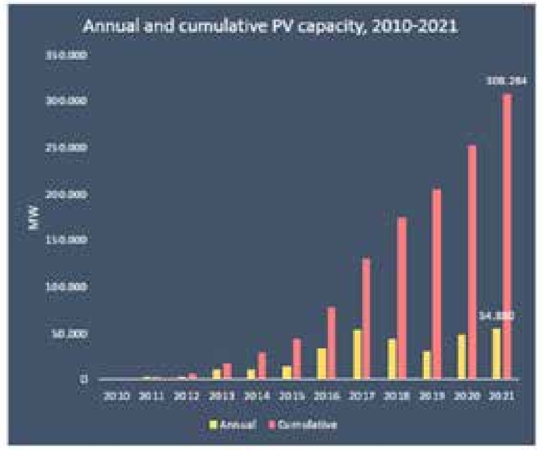
Key drivers to PV deployment

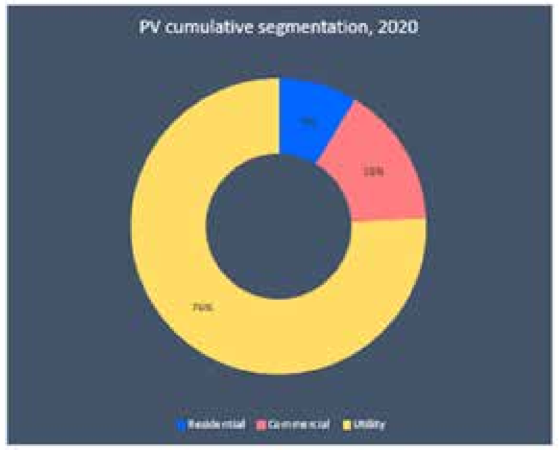
1. The government's priority on energy availability has been a strong support for solar PV (and renewable in general). Indeed, knowing the negative impact that electricity shortages have on the social development of the population, they were avoided at all costs. To do so, the government intended to expand the generation capacities and renewables like wind and solar provided a solution thanks to their low cost and short construction time.
2. The population has a growing demand for clean air, which has been reinforced by the accessible monitoring technologies to access real-time air condition status.
3. The attractive FiT tariff programme was the main direct driver fostering solar PV development across the country. Solar PV across the country could sell their electricity to the State-owned Vietnam Electricity at a rate of USD 93.5/MWh.
4. Developers were allowed to fund their PV installations from different sources, including foreign funding. Developers also were exempted from income tax for 4 years, after which the tax was only progressive for the next 15 years.
5. Equipment was exempted from import tariffs and projects were exempted from land lease.
6. Since its National Strategy for Green Growth from 2012, the government laid down its intention to promote renewables as a strong economic sector for the country, acting as vector for job creation and to foster economic activity.

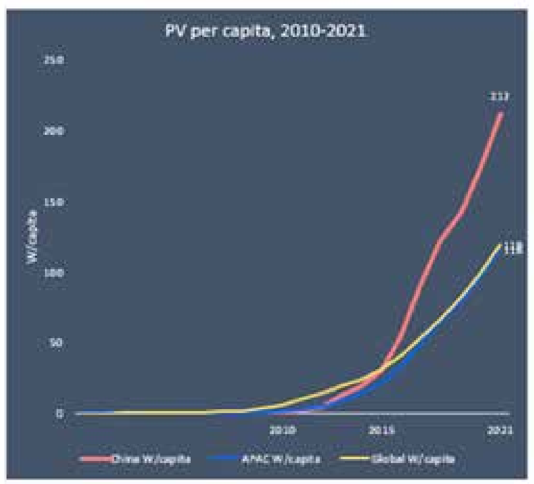
Key barriers to PV deployment:

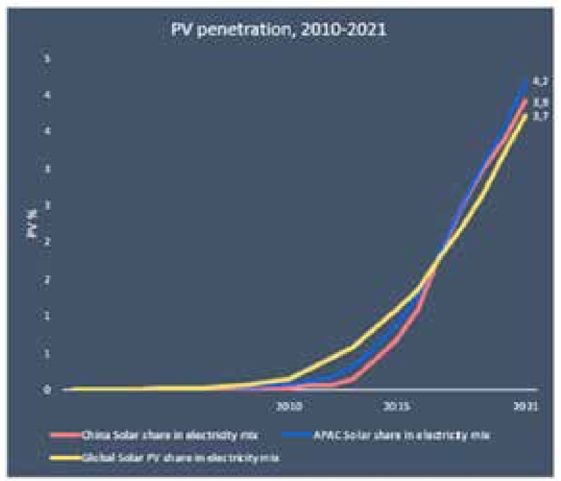
1. Grid constraint and inadequate transmission infrastructure is highlighted as the most important barrier for solar PV development in Vietnam. Following the rapid uptake of solar PV in the country, many projects were rapidly confronted with curtailment issues, putting financial results at risk. Completing a grid expansion project in Vietnam can take up to 3 to 5 years, while a solar PV farm can be deployed in just 6 months. The country needs a specific, precise, and complete plan for the expansion of transmission lines to accompany renewable growth. At the current state, the development is caught in an impasse, whereby transmission operators want to know beforehand where and how much capacity will be deployed, whereas renewable developers need to know in advance what are the areas with proper grid availability to construct their power plant.
2. Following the generous FiT that boosted solar PV, the National Dispatch Center announced that it will not accept any new solar nor wind installation in 2022. Those stop-and-go policies hamper investors' confidence and discourage businesses.
3. The country's complex administrative infrastructure is slowing down the development of projects. Every step of the project need to secure approval from public authorities (up to approval from the Prime Minister for project over 50 MW).
4. For residential rooftop systems, the upfront cost of solar is still often too high for households. In 2019, a 3 kW system would cost around 3,350 USD, which equals around 130% of the GDP per capita.

CHINA









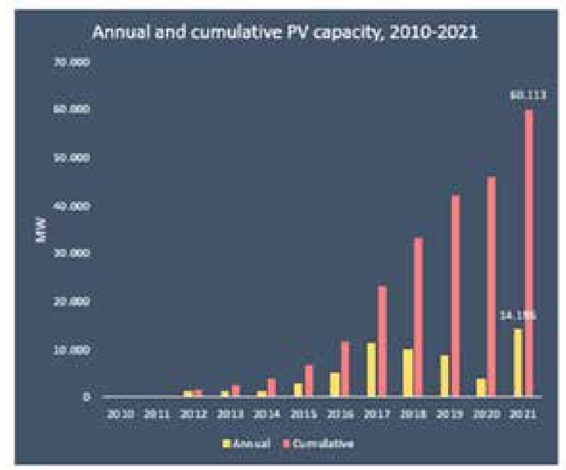
Key drivers to PV deployment

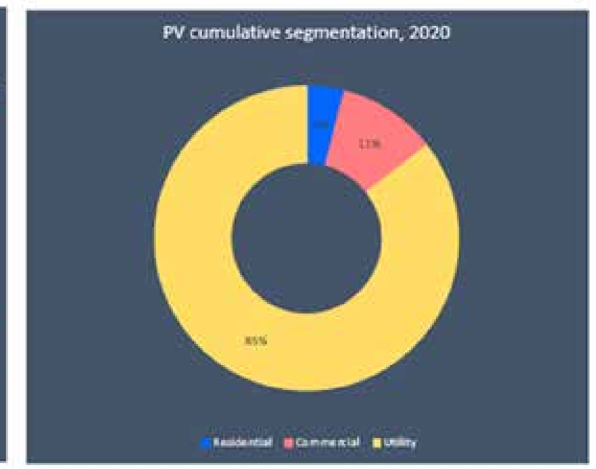
1. China can count on its strong manufacturing industry that was historically dedicated to export toward Europe and the United States. The situation changed following the financial crisis of 2008 when oversees demand dropped. Subsidies were therefore granted to solar manufacturers to support the sector. Then, the manufacturing production capacity grew massively and, since a couple of years, is now turning inward to serve the growing domestic solar PV deployment.
2. With a long-term planning habit and a stable political framework, the Chinese solar PV market does not suffer from stop-and-go policies which can be deadly for the industry.
3. Solar, and renewables in general, are identified as strong assets by the authorities to help the country to reach its climate target. Through its Action Plan for Carbon Dioxide Peaking Before 2030, the country aims to increase the consumption of non-fossil energy to around 20%, and 25% in 2030. The country is also aiming to reach over 1.2 TW of solar and wind capacity by 2030, from 530 GW at the end of 2020.

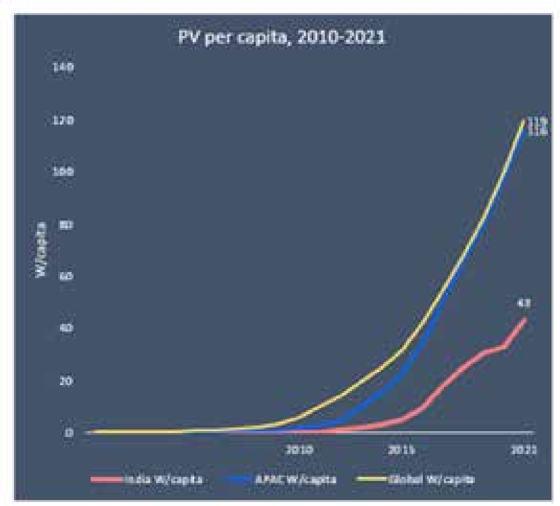
Key barriers to PV deployment:

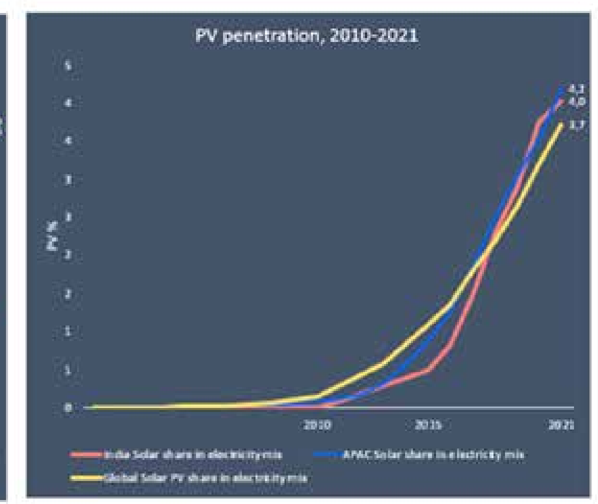
1. Imbalances between the different production levels across the supply chain can lead to an increase in price for solar PV, which negatively impacts developers. This is what happened in 2021 when polysilicon supply capacity fell short compared to the demand, leading to higher prices.
2. In the past, China faced relatively high levels of curtailment rate caused by a lack of grid connection in local areas and imbalances between power supply and demand. As it is expected to see more solar deployment in the coming years, China needs to plan its network expansion effectively to avoid this issue to arise.
3. Investigations carried out by foreign countries over human rights concerns could result in limited exports of Chinese PV products. Solar manufacturers risk lower revenues and ultimately the whole sector could face negative repercussions.

INDIA









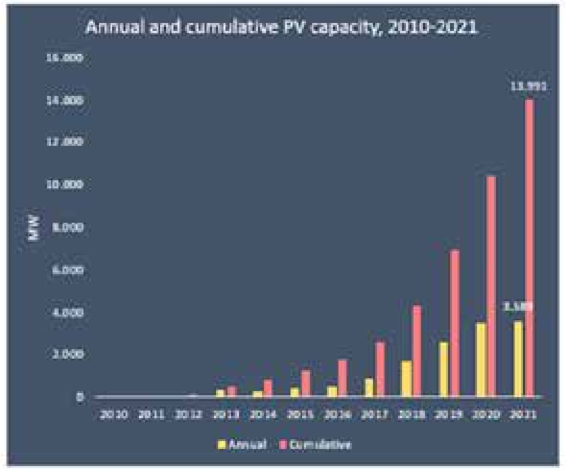
Key drivers to PV deployment

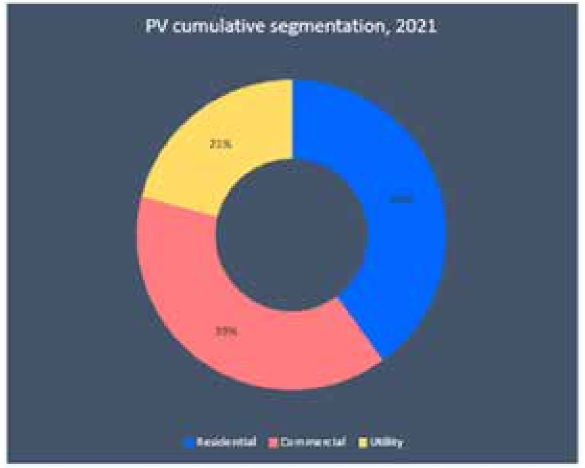
1. The country plans to tap the vast potential for solar PV in the region to achieve its different climate goals, notably: (1) installing 500 GW of non-fossil fuel electricity generation capacity by 2030, from which 280 GW should come from solar PV, (2) sourcing 50% of energy demand from non-fossil fuel sources by 2030, and (3) reduce the emission intensity of GDP by 45% by 2030, from 2005 levels.
2. In the short term, India plans to reach 100 GW of solar PV by the end of 2022, with 60 GW from utility scale and 40 GW from rooftop installations. However, even if deployment level returned to significative amounts in 2021, the country is far from reaching that goal.
3. The Central Electricity Regulation Commission published a draft regulation for General Network Access to Interstate Network which will improve access to the electricity network. The draft document is also reaffirming the Renewable Energy Certificates, which certificates that the electricity produced comes from a renewable energy source.
4. The National Action Plan on Climate Change sets out Renewable Power Obligations, which mandate electricity distributors to generate a defined percentage of their electricity from renewable energy sources. The current requirement is that, by 2022, 21% of the electricity consumed by each state must come from renewables, half of which must come from solar.
5. As a support for solar PV technology, large tenders are launched by the Indian Renewable Energy Development Agency.
6. India is supporting local PV manufacturing through Production Linked Incentives (PLI). The second round of the PLI scheme, approved in September 2022, plans to add 65 GW of fully and partially integrated PV module production capacity, significantly expanding the funding from the first round issued in February 2021. This is expected to boost domestic manufacturing to meet domestic demand as well as exports.

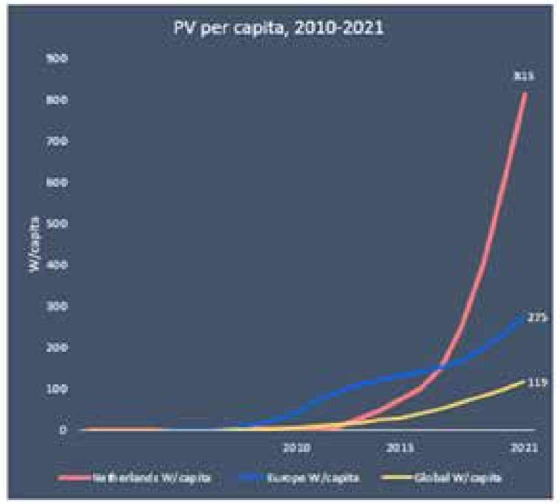
Key barriers to PV deployment:

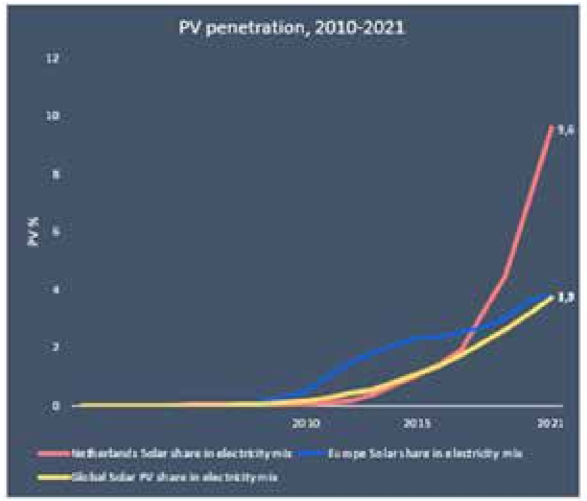
1. The rooftop segment in India is still struggling to take off compared to the utility-scale segment. Most of the installations comes from commercial and industrial clients, while residential installation levels are very low. With the country aiming to install 40% of its total fleet on roofs by 2022, the lack of development in the segment comes as a big gap in the country's solar deployment and a missed opportunity. However, several positive steps are being taken in the right direction, such as the creation of the Central Financial Assistance, an institution dedicated to help households to finance their solar installations. Several states have also implemented various forms of Virtual Net Metering.
2. A new notification issued by the Ministry of finance increased the Goods and Services Taxes (GST), which applies on renewable goods. The increase went from 5% to 12%.
3. The purchasing of modules is currently limited to specific manufacturers that are included in the Approved List of Modules and Manufacturers (ALMM). While the objective of the policy is to foster the domestic manufacturing capacities, this comes at a price for developers, who can only buy from domestic suppliers, whose equipment prices can be costlier than foreign manufacturers. At the same time, India does not have enough domestic manufacturing capacities to supply its whole internal market. Therefore, imports are still being purchased, but face a basic custom duty of 40% for module and 25% for cells.
4. The largest renewable power purchaser in India are power distribution companies (DISCOMs). They are involved in long-term Power Purchase Agreements (PPA) with solar and wind power generation companies. However, in several instances DISCOMs tried to renegotiate or to cancel a PPA contract invoking financial difficulties. This context of unreliable buyers is so far not favorable for the development of a PPAs market in India.

THE NETHERLANDS









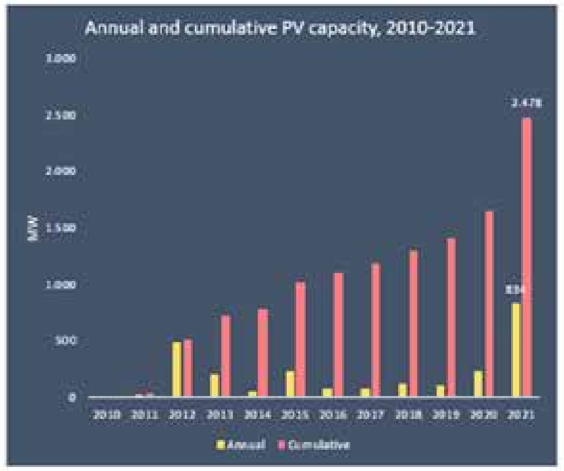
Key drivers to PV deployment

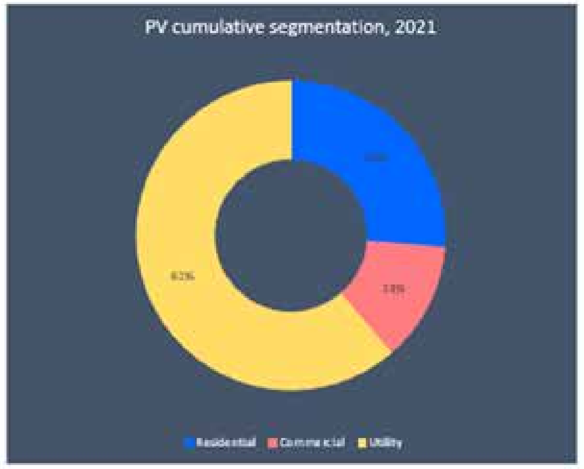
1. The Sustainable Energy Transition subsidy scheme (SDE++) is supporting the development of the larger solar PV projects in the Netherlands. The scheme works as a feed-in premium and grant a financial compensation for producers of renewable energy for every MWh of renewable electricity they generate. It is applicable for renewable energy technology or CO2 reduction technique. The pipeline of awarded projects currently stands at 12 GW.
2. The residential sector is driven by a net-metering mechanism for several years now. This segment has been crucial for the deployment of solar PV in the Netherlands, especially as it also helps to raise awareness among citizens.

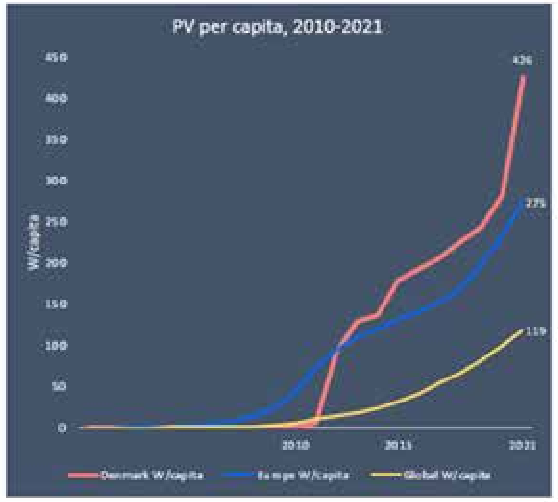
Key barriers to PV deployment:

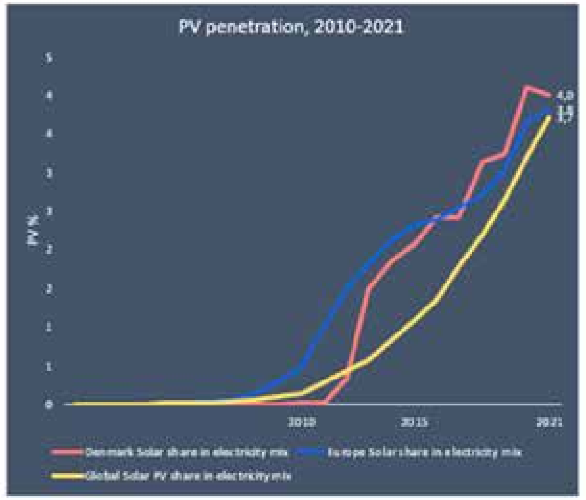
1. One of the potential major barriers for solar PV deployment in the Netherlands is grid congestion. According to local system operators, several regions have already reached the maximum threshold that the current network can allow, meaning that no news projects can be connected. This risks to harm future project completion and increases delays for construction.
2. Another limit is the land availability for the construction of utility-scale projects. In the same line, there is a risk to reduce social acceptance toward solar PV when developers use agricultural lands for energy projects. The local solar sector is looking at different solutions to address land availability and social acceptance, including through the promotion of biodiverse solar and Agri-PV.
3. Even if the annual solar deployment experienced a growth in the past years, the current pace does not seem sufficient to achieve climate neutrality targets, while there are no clear signs of a strong political will to accelerate solar deployment.

DENMARK









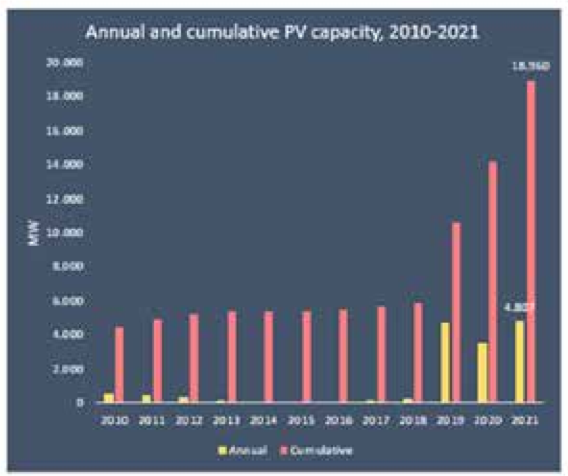
Key drivers to PV deployment

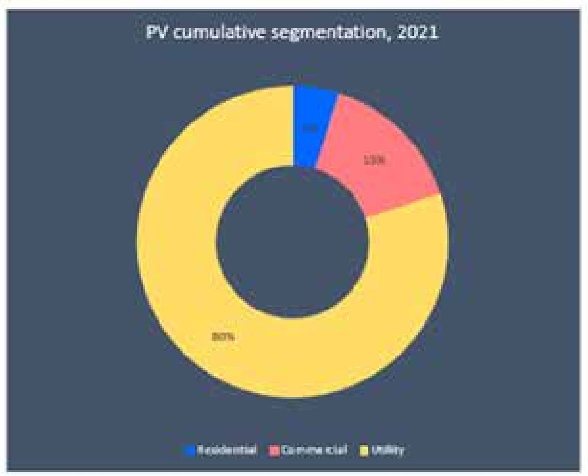
1. Denmark has always been a pioneer country in the development of renewable energy thanks to a continuous political support. In August 2022, the government came to an agreement with Germany to boost the deployment of wind power and green hydrogen. But even in a northern market dominated by wind, solar power is progressively gaining market shares. At present, over 90% of solar's installed capacity comes from subsidy-free utility-scale projects, which reached grid-parity. The sector gained the attention of international investors and holds a pipeline of 16 to 20 GW of utility-scale projects.
2. Despite the market reliance on large ground-mounted PV systems, there are currently no specific restrictions on land usage and no land shortage to hamper the development of the technology.

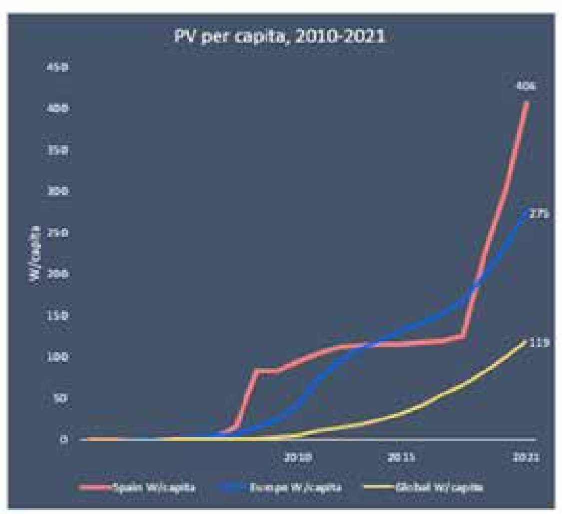
Key barriers to PV deployment:

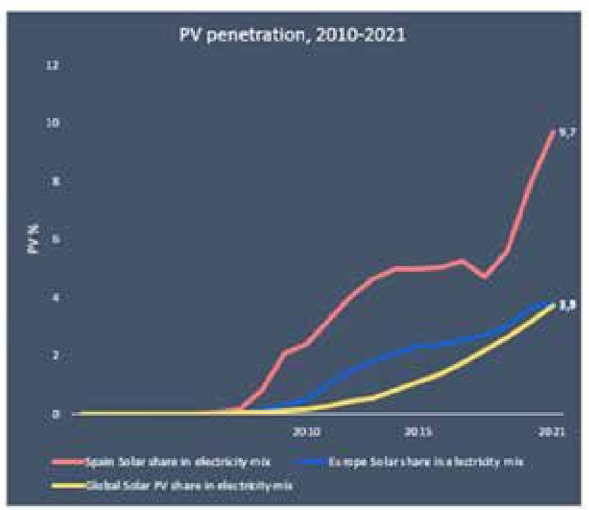
1. The price to secure grid-connection is expected to increase sharply in January 2023 which will make many renewable projects financially non-viable. In the short term, the high electricity price will compensate for the grid connection cost, but it is not expected to be the case in the long-term.
2. While there are tenders to support the development of renewables, the structure of the contract for difference offered in the tenders is judged unbalanced by developers, resulting in zero bids for the latest tender in June 2021. Authorities are therefore now in discussion with project developers to evaluate how to improve those.
3. Rooftop market, and residential in particular, is not as mature as ground-mounted PV. There is no specific support for residential.

SPAIN









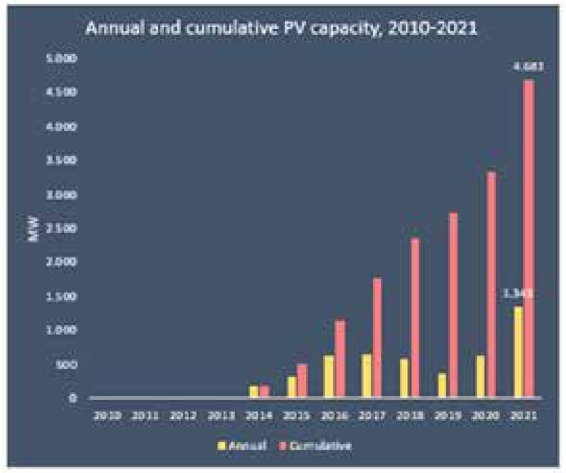
Key drivers to PV deployment

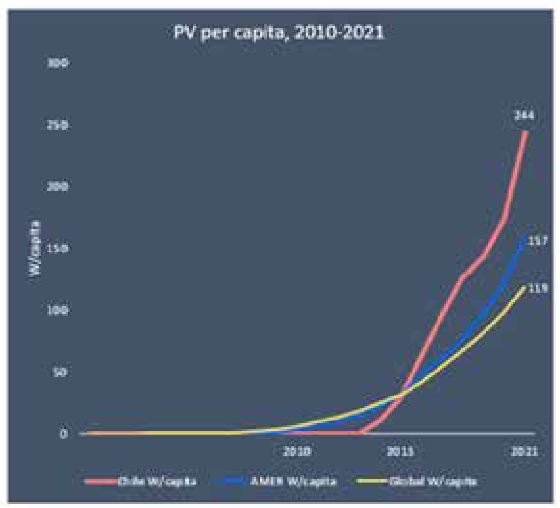
1. The new Climate change Act adopted in 2021 is supporting the deployment of renewable energy sources with two main targets for 2030: a 42% share of renewable in final energy consumption, and a 74% share of renewable in electricity generation.
2. The very high cost-competitiveness of solar PV in the country, both ground-mounted and rooftop solar, provide a strong incentive for solar uptake.
3. The stable framework, abundant solar irradiance, and the vast areas available attracted numerous energy and financial actors which turned Spain into one of the leading solar PPA markets in the world, holding a large amount of projects in the pipeline.
4. The new Roadmap of Self-Consumption, the introduction of tax incentives in different municipalities, and the high electricity prices are gradually pushing the rooftop deployment, which had been limited in the past.

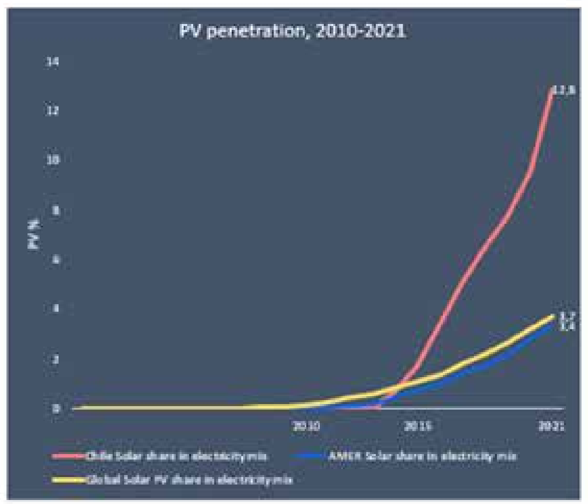
Key barriers to PV deployment:

1. Because of the high volume of solar PV waiting to be deployed in the country, the administrative process is overwhelmed. This burden was further increased with the passing of the Royal Decree-law 23/2020 which mandates that all projects which had secured a network access permits at the time of the decree must obtain the environmental authorization before the end of 2022. This is to force companies to speed up their procedure, but the administration is having a hard time to follow the pace.
2. For rooftop PV, the country lacks homogeneous processes across the different regions. This turn into lengthy procedures to secure permitting, both at the administration and the network levels.
3. With the segmentation being skewed towards large utility-scale projects, an increasing NIMBY effect is starting to be seen among local communities, with several local associations opposing new large ground-mounted solar farms.

CHILE







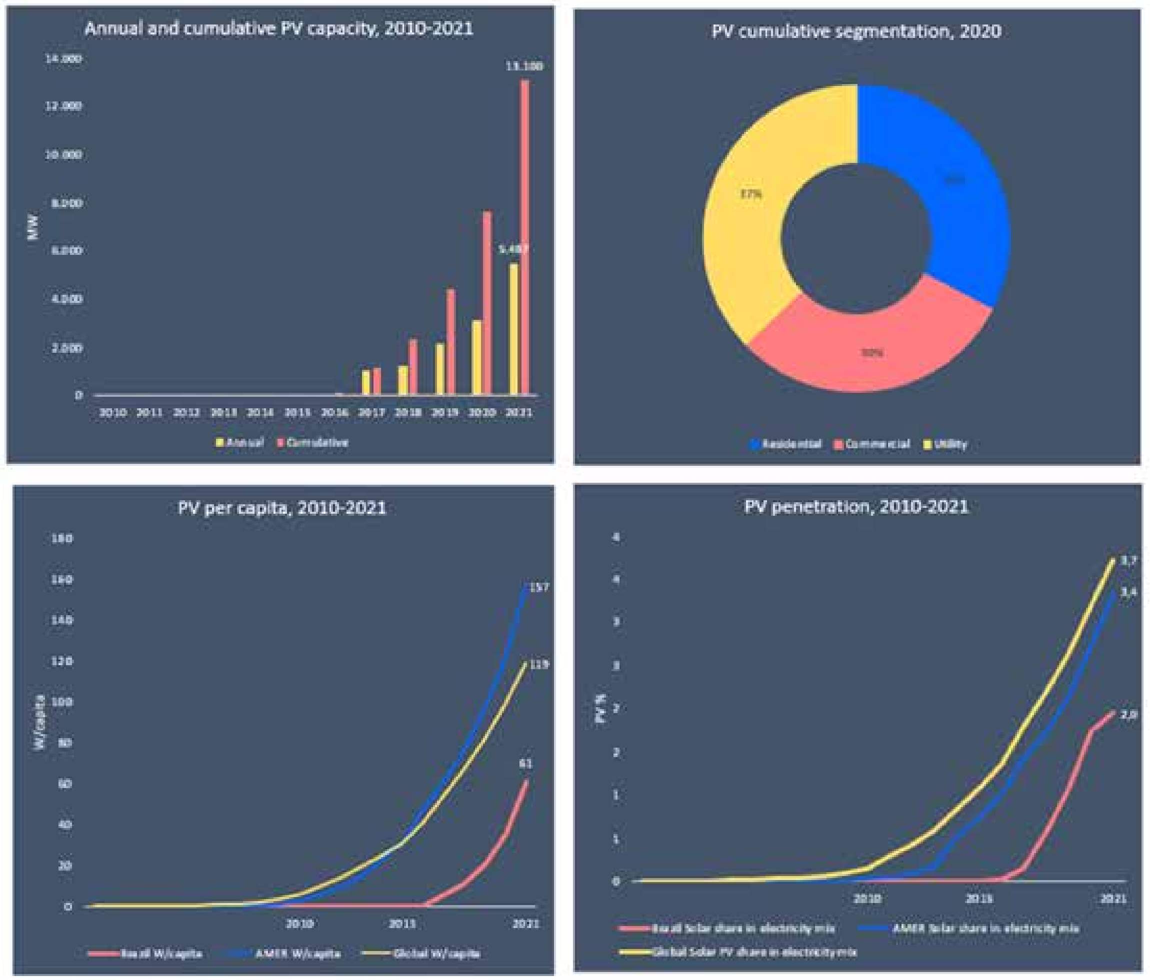
Key drivers to PV deployment

1. The key driver for the Chilean solar market is the utility-scale segment, which is supported by regular tenders and a flourishing PPA market. In 2021 alone, utility-scale projects accounted for more than 70% of new installations.
2. More recently, different pieces of legislations were introduced to support the development of distributed solar PV complementing large PV projects. The Pequeños medios de Generación Distribuida (PMGD), updated in 2020, allows projects up to 9 MW to benefit from a simpler development procedure and introduce a stabilizing price structure to allow developers to sell electricity at a fixed rate. In addition, the net-billing scheme, which is operational since 2014, was updated in 2019 to increase the threshold for eligible projects from 100 kW to 300 kW. Current discussions are aiming to increase again the threshold to 500 kW.
3. Different subsidies and programs also exist to support residential and small commercial to purchase solar PV rooftop systems (Casa Solar, Ponle Energia at tu PYME, etc.).
4. The National Energy Policies aims to generate 80% of electricity from wwwtechnology by 2030, and 100% in 2050. Obviously, solar is expected to play a large role in the energy transition of the country.
5. The new administration elected in 2022 has declared a high level of ambition on environmental issues and seems favourable towards renewable deployment.

Key barriers to PV deployment:

1. Tough the country elected a president willing to take action to protect the environment, the political climate of the country is still largely fragmented. At present, the government does not have a parliamentary majority, limiting its power in the short term. From a business point of view, the country can still be perceived as unstable, which can complicate investment decisions.
2. The country is no home for large manufacturing capacities. Therefore, in a context of inflation, supply chain distortions, and high shipment cost, the development of solar PV capacities can be slowed down or delayed.
3. The geographic configuration of the country – whereby the best climate conditions for solar are in the north of the country while most of the population lives in the southern regions – could pose a challenge to solar deployment due to grid congestion issues. At present, the availability of transmission and distribution grids is limited.

BRAZIL



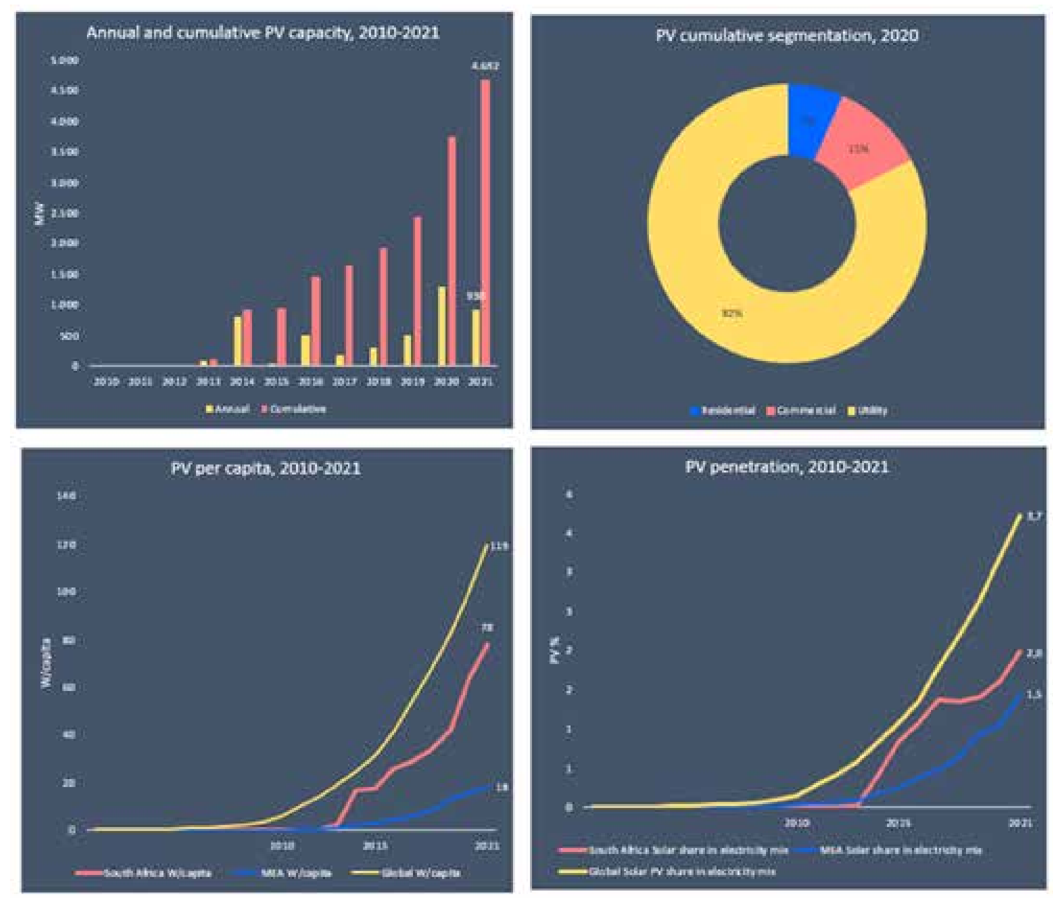
Key drivers to PV deployment

1. Centralised solar PV power is driven by national auctions and a thriving PPA market. Solar proved to be the most cost competitive technology in national auctions, helping to reduce the electricity retail price in the country. Investors have recognised this feature of the technology, which now holds about 35 GW of projects in the pipeline.
2. In recent times, the distributed segment experienced its highest growth ever thanks to an attractive net-metering available for systems up to 5 MW, as defined by the new distributed generation Law no. 14,300/2022. This law brought more legal stability and certainty for investors.
3. Another growing driver in the country is the leasing of solar PV installations for commercial clients. The installation is built and operated by an external developer, in joint venture with the client, and helps the end-user reduce its electricity bills.
4. The recent severe droughts in South America have left empty the available hydro reservoirs. As a result, electricity supply fell and the power price surged. As in many countries, consumers have turned to rooftop PV and self-consumption to reduce their energy bills.

Key barriers to PV deployment:

1. The results of the national auctions have been so far disappointing in the sense that comparably low volumes of solar capacity were contracted. The PPA market has therefore taken over and is now leading utility-scale development. The country is planning further auctions round in 2022, with the hope to see more capacity allocated.
2. Grid capacity is limited and needs to be expanded to integrate the amount of coming renewables.
3. Storage is still facing high taxes and is missing a clear framework that could enable its development.

SOUTH AFRICA



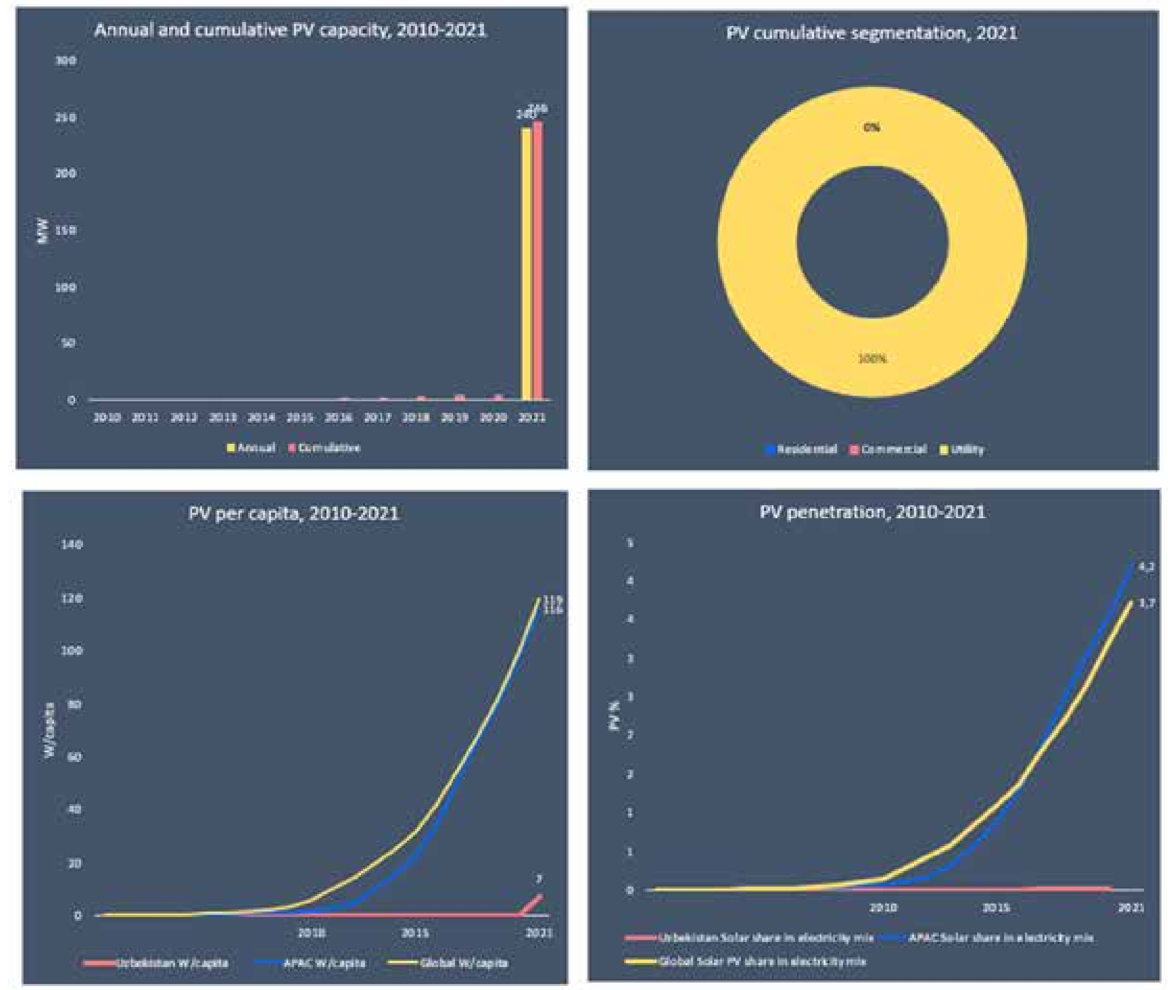
Key drivers to PV deployment

1. South Africa is following its Integrated Resource Plan (IRP 2019), which requires a diversification of the country's energy sources towards more renewables by 2030. It is counting on new installed capacities of 6 GW of utility-scale solar PV and 6 GW of distributed power sources, most of which should be solar PV.
2. The South African Department of Energy is holding regular rounds of tenders under the Renewable Energy Independent Power Producer Procurement Program (REIPPPP). Part of the IRP, the sixth renewable procurement round will allocate 1 GW of solar and 3.6 GW of wind capacity.
3. The threshold under which distributed solar projects are exempted to obtain a license was increase from 1 MW to 100 MW in 2021 and could be completely removed in the near future. The decision was made in order to foster investments in generation capacities and tackle the recurrent loadshedding events in the country. It is also a means for the country to develop solar capacity outside of the tender rounds.
4. A new incentive scheme, which should come in the form of feed-in tariff for commercial and residential installations, is currently under development.

Key barriers to PV deployment:

1. The IRP should be updated to include several intermediary targets to allow for a better policy planning.
2. The sector has been slowed down by the lack of consistency in the procurement rounds of solar PV projects by the government.
3. There are still some challenges at the distribution level to be addressed. The country needs regulations to assure the best safety and quality standards for distributed generation projects.
4. There is a need for innovative funding models to allow the participation of non-traditional investors.

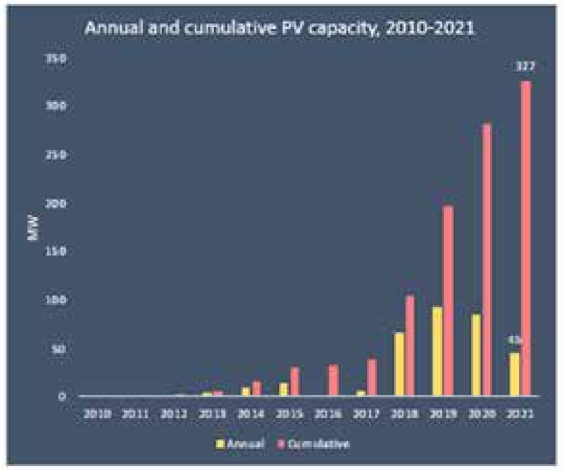
UZBEKISTAN

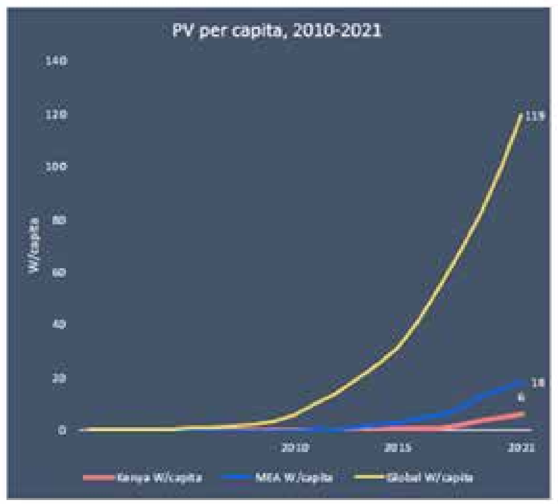


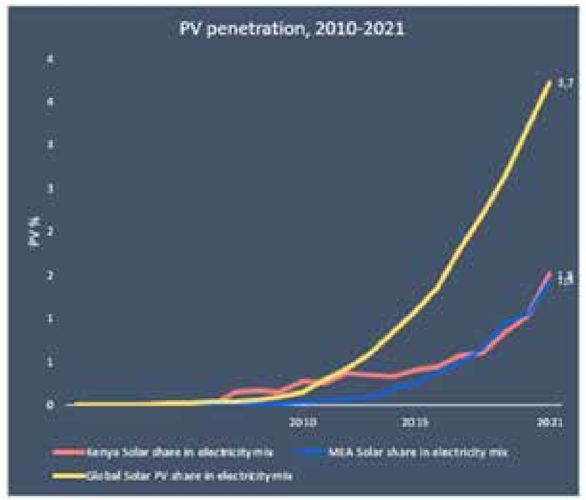
Key drivers to PV deployment

1. 1. Solar PV deployment in Uzbekistan has been supported by leading development finance institutions such as the World Bank, the Asian Development Bank and the European Bank for Reconstruction and Development. Thanks to these entities, the government has completed several round of tenders attracting foreign direct investments. In total, about 10 large-scale projects combining over 2 GW are being tendered starting from 2020, with the first projects starting operations already in 2021.
2. The country put in place several roadmaps to assure the deployment of new power generation to answer the growing electricity needs.
3. Uzbekistan has a target to source 25% of its electricity from renewable sources and to install 4 GW of solar power by 2026 and 5 GW by 2030, with discussions ongoing to increase the latter to 7 GW.

KENYA







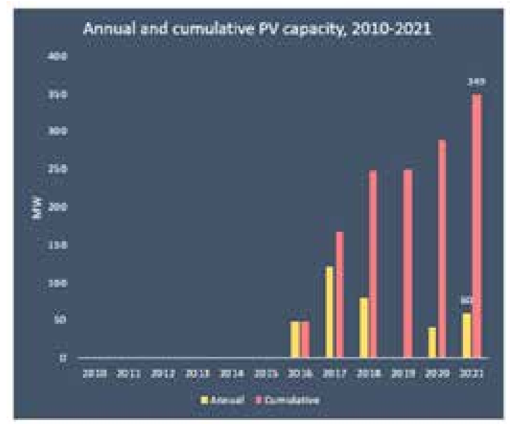
Key drivers to PV deployment

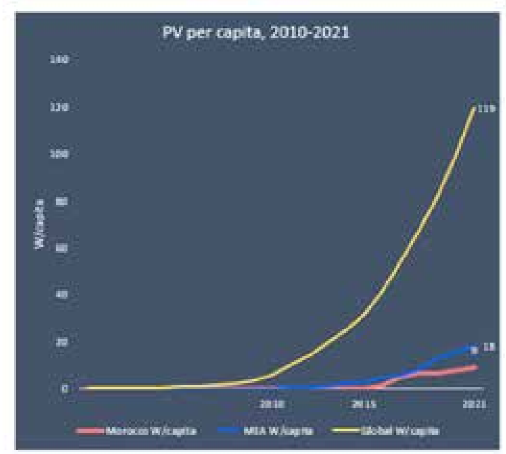
1. The country is home for a large off-grid solar PV market that has accelerated the electrification rate. In order to support the market, the government removed the requirement for a license and is backing up Solar Home Systems deployment. Among others, the Kenya Electricity Sector Investment Prospectus 2018-2022 presented clear investment opportunities to develop off-grid electrification.
2. Kenya launched tenders for small-scale solar PV in 2021. Eligible projects must have a capacity between 300 kW and 1 MW. However, those are not regular exercises, but rather happened on a per-project basis.
3. A net metering scheme for systems up to 1 MW is under preparation, as announced in July 2022, in a draft regulation issued by the Energy and Petroleum Regulatory Authority (EPRA).
4. An auction program for solar is under preparation. This will replace the current FIT that was still applied to PV projects smaller than 20 MW.
5. There is an exemption of VAT and import duties for several renewable energy materials.
6. The country can count of the support of several international financing institutions for the development of larger scale projects.

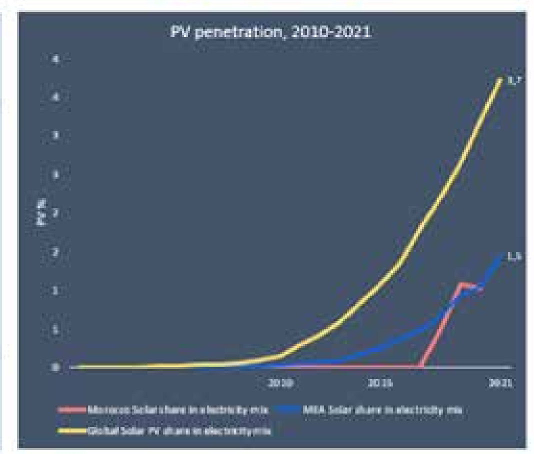
Key barriers to PV deployment:

1. Electricity grids need reinforcement and expansion to accompany solar deployment and reduce network failures.
2. While the off-grid PV sector has seen significant development, on-grid residential systems are still at an early stage of maturity in Kenya. There is a huge potential for solar to meet the energy needs of the country's 54 million inhabitants.

MOROCCO







Key drivers to PV deployment

1. In 2015, the government introduced a net metering scheme as part of the renewable energy law. The scheme is available for solar PV and onshore wind farms connected to high voltage grid.
2. During COP 21, the government increased its climate and energy target, aiming to have 52% of its power generation capacity to come from renewable sources by 2030, up from the previous 42%. Out of this 52%, 20% should come from solar, 20% from wind, and 12% from hydropower. In terms of capacity, the country plans to add 10 GW of RE capacity between 2018 and 2030 (4.6 GW solar, 4.2 GW wind, 1.3 GW of hydro).
3. An important part of the solar capacity is expected to come from the Noor Solar Plants. This project is the largest CSP power station in the world, with about 580 MW. Part of the projects will also include about 70 MW of solar PV. To build it, the government has been holding tenders, the second one was concluded in April 2022.
4. Solar PV also benefits from the fact that the country needs to increase its generation capacity to remedy its high dependence on energy imports and the growing electricity demand.

Key barriers to PV deployment:

1. The fact that net-metering is only available for projects connected to high voltage grid is a severe limitation for the development of small-scale solar PV.
2. On overall, there is no investment supports or programs for small scale PV and most of the expectations solar deployment in the country comes from large solar parks. Residential and commercial solar PV remains unaffordable for locals.

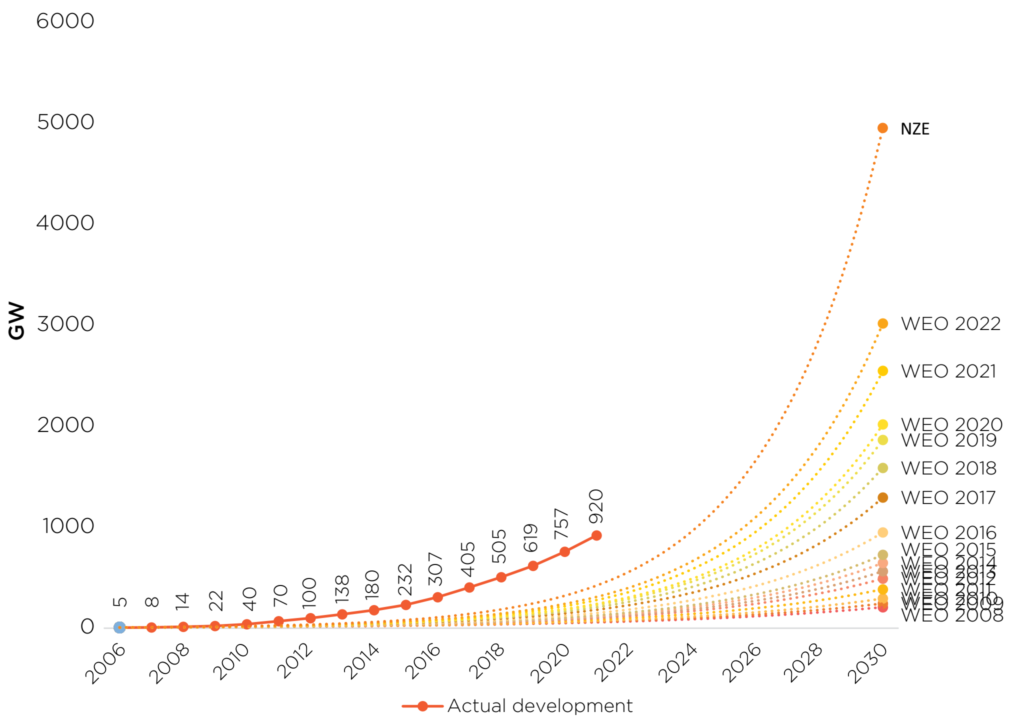
Global Solar Capacity Deployment Scenarios

This chapter provides an analysis of a selection of scenarios depicting future evolution of global solar capacity additions. The analysis includes short (2025), medium (2030) and long (2050) term forecasts on the deployment of solar globally.

The analysis looked at the forecasts provided by a selection of leading solar market analysts, including the studies from different organisations such as the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), energy analysts Bloomberg New Energy Finance (BNEF) and S&P IHS Markit (IHS), the European PV industry association SolarPower Europe (SPE), as well as long-term energy modelling research groups from the academia.

Anticipating the evolution of solar markets is a difficult task, since many factors can impact positively or negatively their performance. These are not limited to changes in the policy framework or technology and cost improvements, but also include macroeconomic trends that go beyond the solar sector alone. One example is the COVID-19 health crisis, which severely affected many countries around the world and limited the movement of people and goods, disrupting supply chains and leading to project delays and cancellations. The global solar market is rapidly growing, yet potentially very volatile. For this reason, even in a relatively short-term perspective, solar analysts' forecasts show significant differences. This uncertainty is exacerbated when broadening the temporal perspective to the medium and long term. Nevertheless, looking back in time to previous forecasts provided by the World Energy Outlook (WEO), the IEA's flagship report, it appears clearly that solar PV development was largely underestimated (see Fig. 58). While the solar sector reached 757 GW in 2020, the first "central scenario" forecasts from 2008-2011 predicted a timid 72 to 184 GW. Previsions have continuously been revised upward but the scale remains too small. The cumulative PV fleet in 2020 was already higher than what the WEO 2016 expected it to be in 2025.

Fig 58. IEA World Energy Outlook forecasts versus actual historical development of solar PV

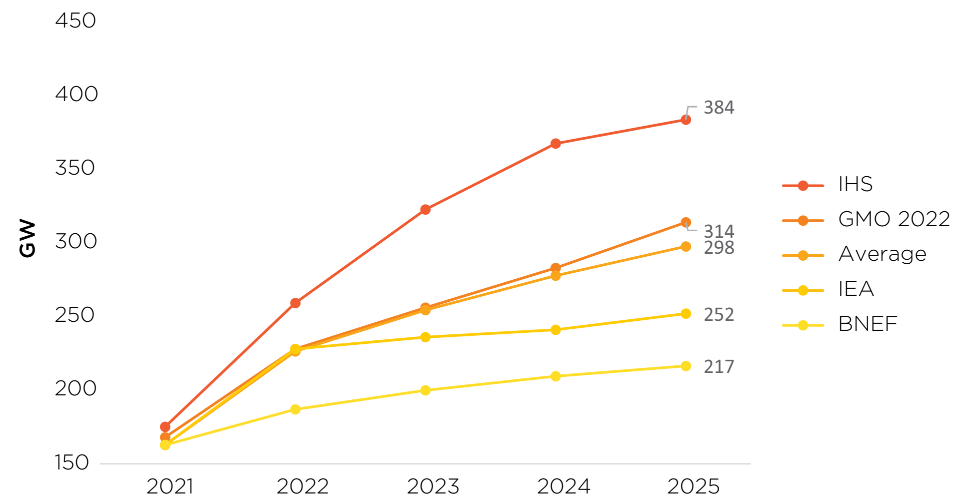


Source: IEA (note on scenarios considered: WEO 2008 and WEO 2009 is the "reference scenario"; WEO 2010 to 2018 is the "New Policies scenario"; WEO 2019 to 2022 is the "Stated Policies scenario"; NZE is the "Net Zero Emission" scenario)

4.1. Short Term (2025)

From the 163 GW annually installed in 2021, the world's solar market is expected to grow 83% to 298 GW by 2025 (Fig. 59). This is the average growth expected by different solar analyses, although individual forecasts stand significantly below or above this level. At the lower end of the spectrum, the IEA, which has traditionally been quite conservative in its solar forecasts, anticipates a market of 191 GW in 2025, up 17% from 2021 levels, in its main scenario. S&P Global's IHS Markit provides the most optimistic forecast, with 384 GW deployed by the same year, equivalent to a 119% increase, in its main scenario, while SolarPower Europe's Global Market Outlook 2022-2026 Medium Scenario follows with 314 GW (+ 87%). BNEF's central scenario anticipates strong growth in 2022 followed by marginal growth in the following years, landing at 252 GW by 2025.

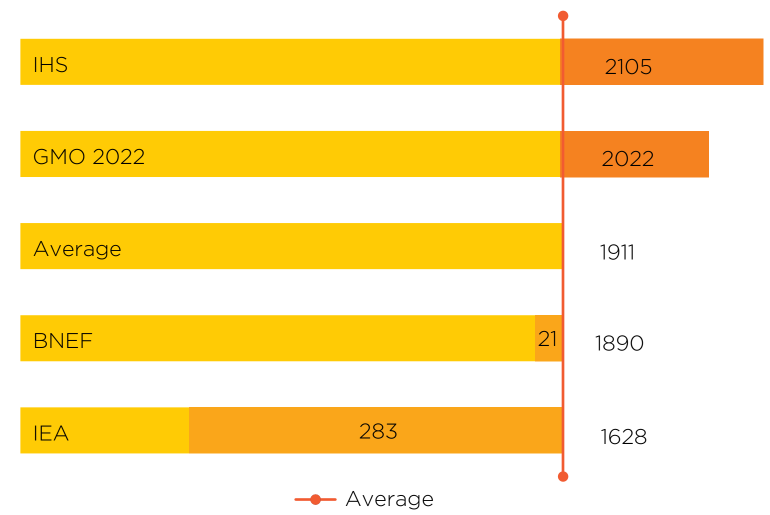
Fig 59. Annual global solar PV scenarios until 2025



Sources: BNEF, IEA, IHS, IRENA, SPE

The cumulative PV capacity scenarios for 2025 reflect the differences in the annual market scenarios (see Fig. 60). IHS Markit and SolarPower Europe anticipate that the total operating PV capacity by that year will have exceeded 2 TW (more precisely, 2,105 and 2,022 GW respectively). This would mean a doubling of the existing solar fleet in less than 4 years, considering that the TW mark was reached in April 2022. On the more conservative front, BNEF expects 1,890 GW, while the IEA forecasts only 1,628 GW. On average, it is expected that 1,911 GW will be installed worldwide by the end of 2025.

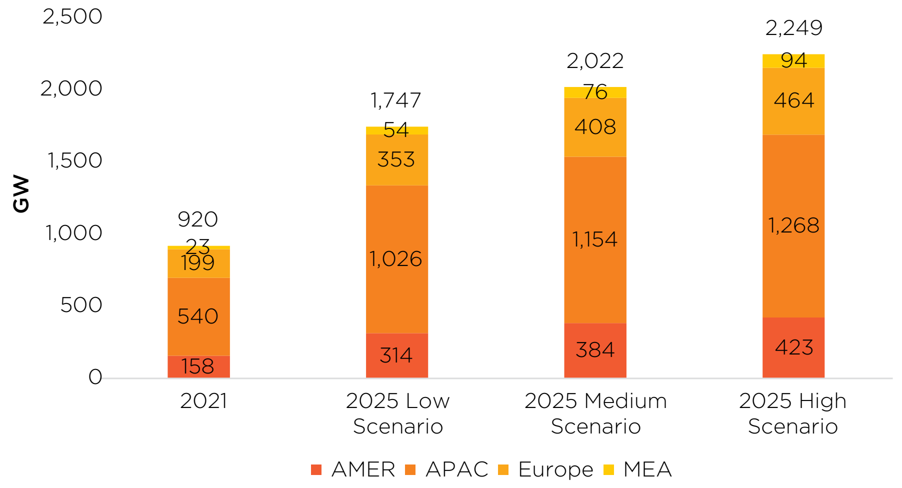
Fig 60. Total installed capacity scenarios in 2025



Sources: BNEF, IEA, IHS, IRENA, SPE

Figure 61 displays the evolution of regional distribution of total installed solar PV capacity in the timeframe 2021-2025 under SolarPower Europe's three GMO scenarios. Despite the growth in absolute terms, the geographic allocation of solar capacity is poised to remain overall stable in all three scenarios. The APAC region, which in 2021 contributed more than half (57%) of the solar operating fleet, maintains a major share between 56-59%. Europe, currently at 22%, will remain second, although it will lose one or two percentage points to the Americas, whose share will increase from 17% to 18-19%. The MEA region will not only increase its PV capacity in absolute terms, but its global share will grow from 3% to 4% in two of the three scenarios.

Fig 61. Total solar PV installed capacity 2021 and 2025



Source: SPE

Solar applications other than on-grid solar are also expected to grow in the short term.

Solar PV off-grid capacity, which stood at 9 GW in 2021, is anticipated to grow 274% to 33.5 GW by 2025 (Fig. 62a). It must be noted that some analysts include PV dedicated for hydrogen in off-grid numbers, resulting in high differences between forecasts. Against this background, In the medium to long term it becomes increasingly complicated to distinguish between on- and off-grid solar PV, as the system application moves from traditional off-grid applications like SHS and minigrids to multi-GW e-fuel production plants.

Concentrated solar power deployment is also expected to continue, though at a slower pace than grid-connected and off-grid solar PV. The 6.4 GW of cumulative CSP capacity are poised to grow 34% to 8.6 GW by 2025 (Fig. 62b).

Europe, currently at 22%, will remain second, although it will lose one or two percentage points to the Americas, whose share will increase from 17% to 18-19%.

Fig 62a. Solar PV off grid - Total installed capacity 2021 and 2025

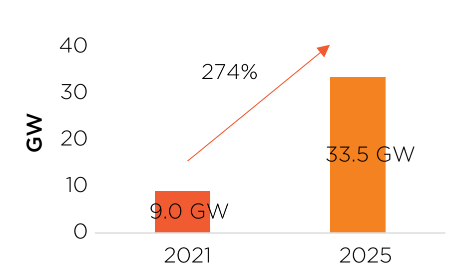
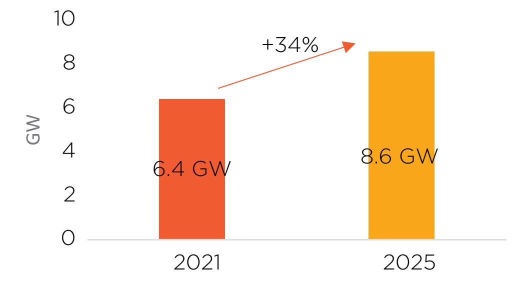


Fig 62b. CSP - Total installed capacity 2021 and 2025



Source: SPE, IEA, IHS

4.2. Medium term (2030)

While several stakeholders provide forecasts of PV market evolution in the short term, only a limited number of medium to long term forecasts are available. This is a consequence of the fact that longer term forecasts are a much more difficult task. Due to the longer timeframe under scope, those forecasts cannot rely on current market dynamics and foreseeable policy and regulatory trends. To overcome this challenge, the studies taken into examination use a top-down approach based on climate and energy objectives in the long term (2050), most of them looking into 2030 as an intermediate milestone.

The medium-term analysis includes the academic research from LUT University in Finland and Australia's University of Technology Sydney (UTS), which are among the universities whose energy system modelling groups have studied the transition to 100% renewable energy systems at the global scale. LUT carries out a cost-optimization modeling based on the objective of achieving 100% renewable energy by 2050, determining cost-efficient pathways to achieve this target.[3] UTS, in cooperation with the German Aerospace Center (DLR), employs a simulation approach for long-term energy system modelling, whereby pathways to global 100% RE systems with a focus on technological diversification are analyzed. A third scientific study looking at global 100% RE systems in 2050, from Stanford University, does not include an analysis of transformation pathways from the current state of play, but rather provides a greenfield optimal 100% RE system in 2050. For this reason, the study is not included among the medium-term scenarios due to data unavailability, but is considered in the long-term scenario analysis.

A second group of studies that are included in this assessment comes from other non-academic groups, including intergovernmental organisations International Energy Agency (IEA) and International Renewable Energy Agency (IRENA), and energy consultant Bloomberg New Energy Finance (BNEF). Differently from the academic papers taken into account, these studies do not model 100% RE energy systems, but have other long-term goals. The IEA Net Zero Emissions by 2050 (NZE) Scenario from the World Energy Outlook 2021 aims to limit GHG emissions to net-zero by 2050, while IRENA's 1.5°C Scenario from the World Energy Transition Outlook 2022 has the objective to comply with the 1.5°C goal from the Paris Agreement. BNEF's Green Scenario from the New Energy Outlook 2021 meets the Paris Agreement and achieves net-zero emissions in 2050.

[3] Although these are not the only two studies that analyze the global energy transition in the 2030 and 2050 timeframes, they have been chosen for the extensive publicly available data included. An overview of scientific papers investigating the global energy transition by 2050 is provided in figure 67, section 4.3.

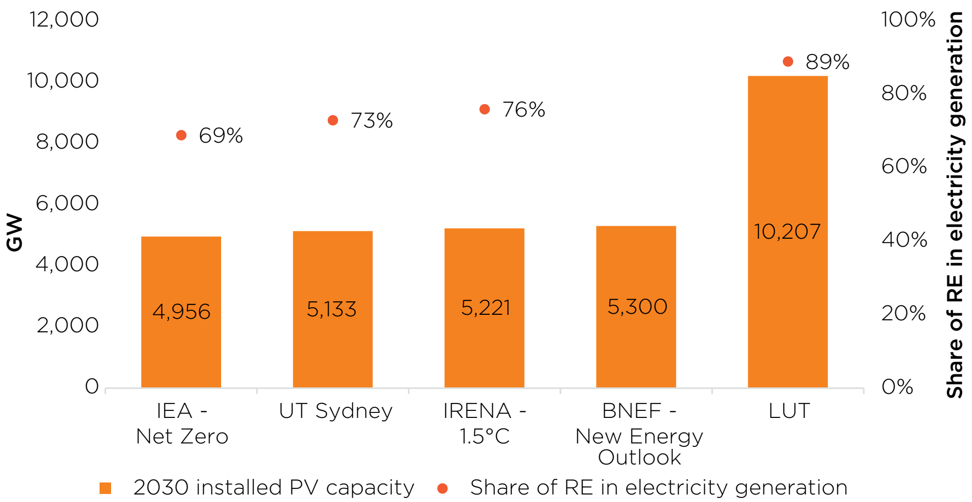
An overview of the scenarios included in the medium and long term analysis is provided in Table 7.

Table 7 – Overview of long-term studies included in the 2030 and 2050 analysis.

Organisation	Title	Category	Scenario	Year	Goal	2030 data	2050 data
LUT	Low-cost renewable electricity as the key driver of the global energy transition towards sustainability	Academic	Best Policy Scenario	2021	100% RE by 2050	V	V
UTS	Achieving the Paris Climate Agreement Goals - Global and Regional 100% Renewable Energy Scenarios with Non-Energy GHG Pathways for +1.5°C and +2°C	Academic	1.5°C Scenario	2019	100% RE by 2050	V	V
Stanford	Low-cost solutions to global warming, air pollution, and energy insecurity for 145 countries	Academic	100% WWS	2022	100% RE by 2050	X	V
IEA	Net Zero by 2050	Intergovernmental	NZE	2021	Net-zero emissions by 2050	V	V
IRENA	World Energy Transitions Outlook 2022	Intergovernmental	1.5°C Scenario	2022	Meet Paris Agreement at 1.5°C by 2050	V	V
BNEF	New Energy Outlook 2021	Consultant	Green Scenario	2021	Meet Paris Agreement, net-zero emissions by 2050	V	V
DNV	Energy Transition Outlook 2022	Consultant	1.5°C Scenario	2022	Net-zero emission and 1.5°C by 2050		

Figure 63 illustrates global solar PV installed capacity in 2030 according to the long-term scenarios described above. In these studies, 2030 is not considered as the final timeframe to achieve decarbonisation goals, but rather the intermediate milestone to reach the 2050 objectives. In four out of five scenarios assessed, solar PV capacity increases from the 1 TW installed in 2022 to about 5 TW in 2030; more precisely, the estimates range between 4.96 TW from the IEA and 5.3 TW from BNEF. The fifth scenario is significantly more ambitious than the others: with 10.21 TW of PV deployed worldwide by 2030, the LUT scenario anticipates more than twice the solar capacity installed in the other four scenarios.

Fig 63a. Scenarios for total installed capacity of solar PV in 2030

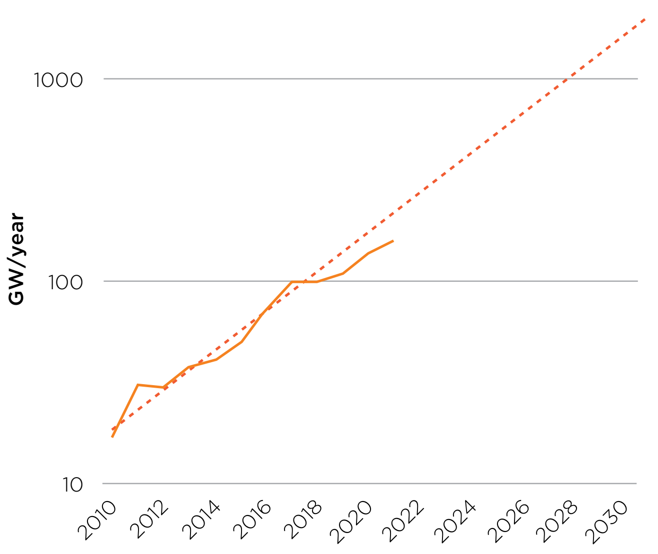


Sources: BNEF, IEA, IRENA, LUT, UTS

Differences in the scenarios can be attributed to a number of factors. One important factor is the level of ambition towards the penetration of renewable energy in the electricity mix, and the contribution of solar energy to the share of renewable power. As can be seen in Figure 63, the there is a positive correlation between the RES share in electricity generation and the deployed PV capacity. The IEA scenario achieves a RES-E share of 69%, while the LUT scenario reaches 89%.

While differences in estimations exists and some modeling can appear very large – especially LUT –, extrapolating trends from the past highlights that solar PV deployment has been faster than expected, and that analysts in general underestimated the deployment of the technology. Looking at the learning curve in Figure 63b, solar installations almost double every three years, and it is not unrealistic to expect a TW-size annual market by 2030.

Fig 63b. Toward a 1TW annual global market by 2030

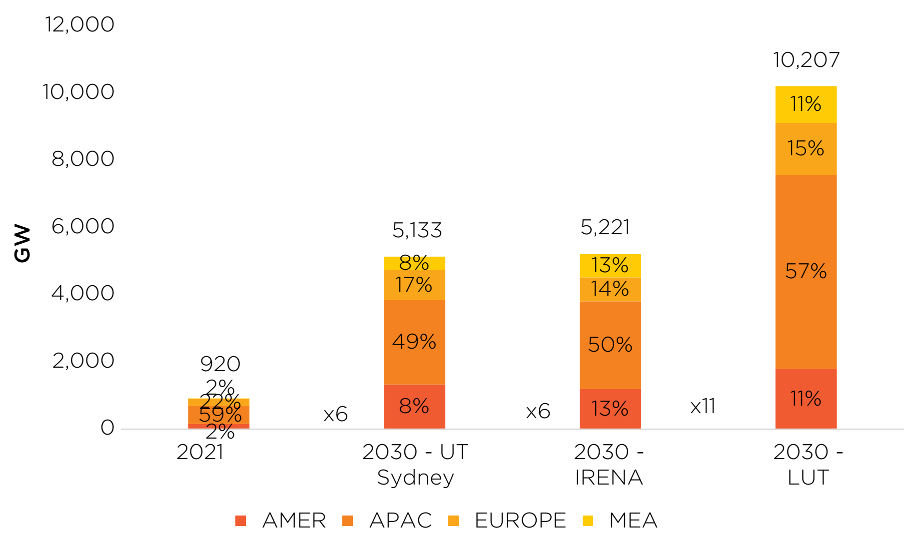


Source: SPE, IEA, IRENA, Bloomberg, HIS.

Out of the five mid-term scenarios taken into consideration, the UTS, IRENA and LUT scenarios provide details on the regional breakdown of PV installed capacity in 2030 (Fig. 64). Although some common characteristics can be seen across the three scenarios, the LUT scenario has significant differences from the other two. The UTS and IRENA scenarios anticipate a noteworthy change in the shares of regional allocation compared to today. Although the APAC region remains in control of the largest PV capacity, its relative share decreases from 58% in 2021 to 49-50%, equal to 2.5-2.6 TW. In both scenarios Europe loses the #2 rank, decreasing its relative share from 22% to 14-17% (715-892 GW). That role is taken by the Americas, who grow their share from 17% to 23-26%, equivalent to 1.2-1.3 TW. A significant growth is seen in the MEA, whose share increases from 3% to 8-13% or 402-703 GW by 2030.

The LUT's scenario, on the contrary, projects that both APAC and AMER retain their PV share in 2030, with a slight decrease by 1% each to reach respectively 57% (5.7 TW) and 18% (1.8 TW). The significant difference in this scenario is that MEA's growing market share from 3% to 11% is mostly at the expense of the European market share, which drops from 22% to 15%. The MEA region reaches 1.1 TW and Europe 1.5 TW. Similarly to the UTS and IRENA's scenarios, this causes Europe to lose its second place in the profit of the AMER region. APAC remains the largest region and MEA the smallest.

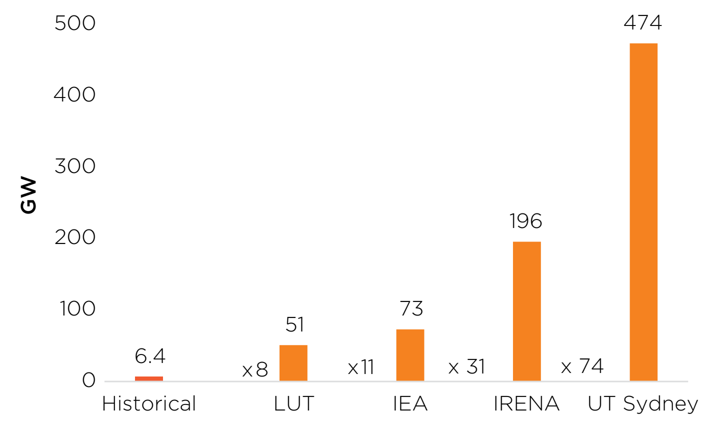
Fig 64. Regional distribution of total solar PV capacity in 2030



Sources: SPE, UTS, IRENA

While solar PV has a primary role in all these scenarios, four of them – namely, the scenarios from the IEA, IRENA, LUT and UTS – also estimate the evolution of CSP capacity by 2030. Figure 65 displays the expected growth in total CSP installed capacity by 2030 according to these scenarios. At the lower end of the range, the LUT Best Policy Scenario projects 51 GW of CSP deployed by 2030. IEA's NZE Scenario is somewhat higher, at 73 GW; IRENA's 1.5°C Scenario estimates 196 GW, while UTS stands at the upper end with 474 GW installed by the same year, driven primarily by the technology diversification approach used in the study. These scenarios imply a capacity increase of 8, 11, 31 and 74 times respectively from the 6.4 GW installed in 2021.

Fig 65. CSP - Total installed capacity scenarios 2030



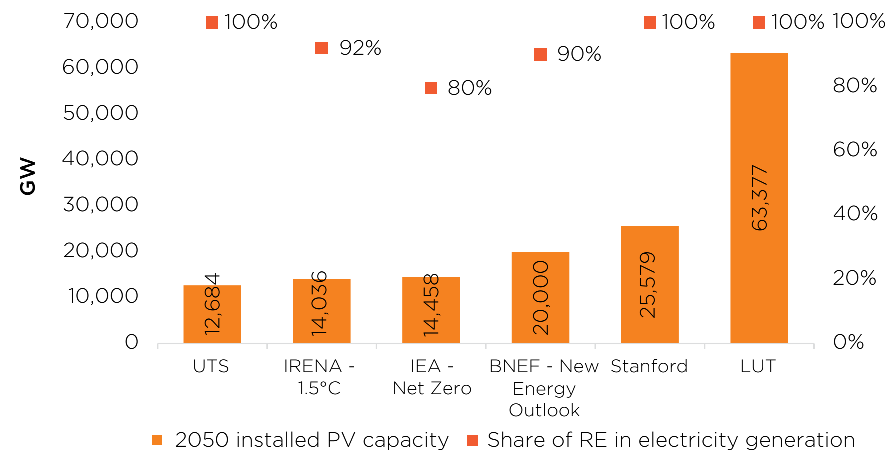
Source: IEA, IRENA, LUT, UTS

4.3 Long term (2050)

If the previous section looked at medium-term solar PV deployment in the timeframe 2030, this section provides an overview of deployment scenarios in the long term, using 2050 as a reference year to achieve global climate goals. The scenarios considered in this analysis include the five scenarios illustrated in the previous paragraph, with the addition to the scenario developed by Stanford University's energy modelling team. Like the other scenarios from academia, the Stanford scenario describes the pathway for the achievement of 100% renewable energy by 2050 goals. Although the study sets a milestone on renewable energy shares in 2030, specific data on solar deployment by that year is not publicly available – this is the reason why it has not been included in the medium-term analysis.

Long-term solar PV deployment scenarios are presented in Figure 66. According to the scenarios, global solar PV operating capacity in 2050 ranges between 12.7 TW (UTS) and 63.4 TW (LUT). The second highest PV capacity comes from the Stanford scenario and stands at 25.6 TW, while the BNEF scenario expects 20 TW of solar capacity deployed. The IRENA and IEA scenarios, towards the lower end of the spectrum, come to very similar results – 14.0 and 14.5 TW respectively.

Fig 66. Scenarios for total installed capacity of solar PV in 2050



Sources: BNEF, IEA, IRENA, LUT, Stanford, UTS

The broad differences in the scenario results can be explained by a number of different factors, including the objectives set in each of these scenarios, the different methodologies, scope and modelling systems used, the technology and cost assumptions, and other parameters that can have a significant impact on the scenario results.

A first important distinction to consider is the level of ambition by 2050. As previously introduced, the energy system modelling from UTS, Stanford and LUT all target the achievement of 100% renewable energy systems by 2050, whereas the IEA, BNEF and IRENA scenarios have a lower level of ambition, with RE shares standing at 80%, 90% and 92% respectively. A lower RES share in the energy system implies the use of fossil sources with carbon capture and storage (CCS) and nuclear energy, which limit the demand for renewables. Similarly, what the achievement of the Paris Agreement and net-zero emissions means differ significantly across the scenarios, depending on what carbon emissions and carbon sinks are taken into account.

Second, different expectations in terms of future energy demand – in particular electricity demand – bring very different outputs from the models. This includes different assumptions regarding future global energy needs in terms of average individual consumption. Importantly, modelling a high level of energy-efficient electrification drives the need of renewable electricity from solar and wind while reducing the demand for fossil fuels. One major driver for higher renewable electricity volumes comes from sector coupling. This consists of the direct use of renewable electricity, or its indirect use using hydrogen as an energy carrier, in the transport and heating sectors. Power-to-X demand to decarbonize hard-to-electrify sectors, such as aviation, maritime and energy-intensive industry, drives up the deployment of solar and wind capacity. Strong differences in energy demand assumptions and results can be found not only between the 100% RE scenarios and the other scenarios, but also among the 100% RE scenarios.

A third set of important factors influencing the study results are the technology options included in the assessment, the temporal and geographic granularity of the model, the end-use sectors covered and the overall boundaries of the analysis. Increasing the simplification of the model can bring low temporal and spatial resolution, limited choice of available technologies, and can ultimately lead to implausible results. A case in point regarding the end-use sectors

The IEA scenario anticipates 630 GW of solar annually installed by 2030, up from 163 GW installed in 2021; however, it expects the market not to expand further post 2030 and to actually decline until 2050. The IRENA scenario expects on average 440 GW per annum in the timeframe 2030-2050, which appears a highly conservative assessment compared to the state of play of the market today

covered can be made for the chemical sector, which requires renewable electricity for the decarbonisation of its feedstock. Crucially, a cost-optimization model will deliver very different results than a simulation model that pays more attention to other aspects, such as technological diversity.

Technology and cost assumptions also play a key role, including on the breakdown of renewable energy sources chosen by the models to meet energy demand. In global 100% RE studies, different assumptions on the cost reduction curves for wind and solar can bring solar-dominated or wind-dominated scenario results. Other important cost assumptions regard batteries, electrolysers, as well as other non-RE technologies such as CCS.[4]

The result of different assumptions can be seen not only between the 100% RE scenarios and the other scenarios, but also among the 100% RE scenarios. The LUT scenario, in which low-cost solar, batteries and electrolysers drive up the demand for PV electricity, has a 76% share of PV in the 2050 energy mix. The Stanford scenario, more wind-oriented, results in a PV share of 19% by 2050. The UTS scenario lands somewhere in between, with a 45% PV share in the energy mix by 2050. Under this perspective, the role of solar is central in the UTS scenario, despite it has the lowest PV capacity volumes deployed in absolute terms.

The scenario results can be also examined looking at the annual PV installation levels required to reach the 2050 goals. The IEA scenario anticipates 630 GW of solar annually installed by 2030, up from 163 GW installed in 2021; however, it expects the market not to expand further post 2030 and to actually decline until 2050. The IRENA scenario expects on average 440 GW per annum in the timeframe 2030-2050, which appears a highly conservative assessment compared to the state of play of the market today. By contrast, the LUT scenario anticipates about 3 TW of annual PV installations in the 2040s, a volume that has been taken up among solar PV experts.

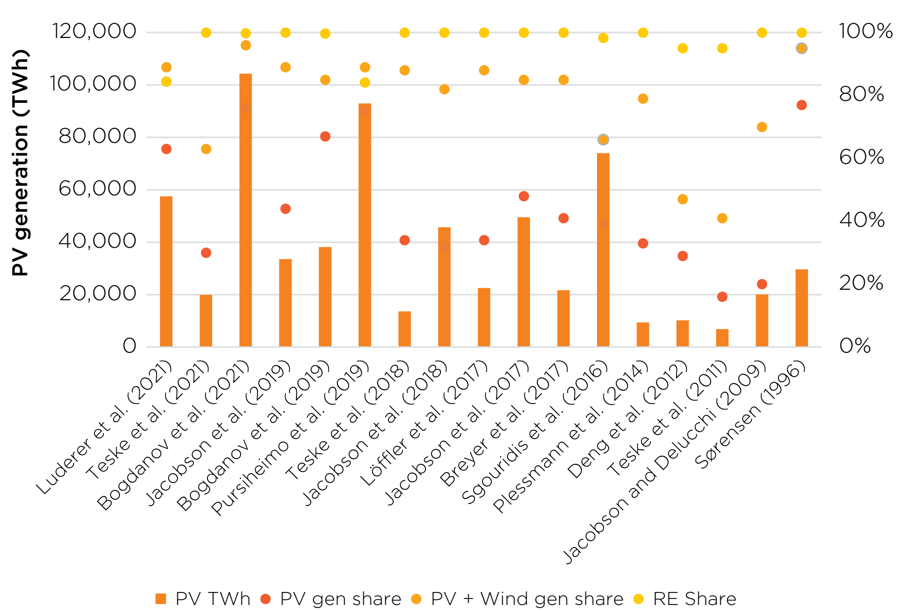
[4] Importantly, technology assumptions should be reflective of resource availability and cost-competitiveness in the areas where most of energy demand will come from. For example, a high reliance on wind power, as done in the BNEF study, can be questioned, since 70% of the world population lives in countries with high solar irradiation, where the availability and cost-competitiveness of solar power is much higher.

The global polysilicon manufacturing capacities expected by 2025 are close to 1 TW of production per year, showing that the PV industry is aligned with this pathway.

While LUT, UTS and Stanford are the academic studies included in this analysis because of data availability and prominence in the international energy system modelling discourse, many other academic researchers have investigated the transition to 100% renewable-based global energy systems. The overview provided in Figure 67 illustrates the role of solar PV in terms of absolute electricity generation and its share of electricity generation in 2050.[5] The studies, listed by publication date, include analyses dating as early as 1996, although the majority has been published within the last 5 years. Advanced cost-optimized energy system modelling usually results in wind + solar shares of about 90% of electricity supply. All the 100% RES studies with high PV shares above 60% anticipate a continued decline in the cost of PV technology. Studies with lower shares of solar typically have higher PV and lower wind cost assumptions, or add constraints to the models to include into the mix other sources like CSP or bioenergy.

Looking at the PV generation levels, the LUT scenario, hereby indicated as Bogdanov et al. (2021), has comparable results with its peers using similar assumptions. Nearly all academic studies published since 2018 find PV generation volumes around 40,000 TWh or higher, corresponding to 22-27 TW of installed capacities. Two studies finding around 100,000 TWh of PV electricity have 49-63 TW of solar PV capacity deployed. The only exception is the UTS research group, hereby indicated as Teske et al., who models a large expansion of CSP that lowers the PV share.

Fig 67. PV generation in global 100% RE system analyses



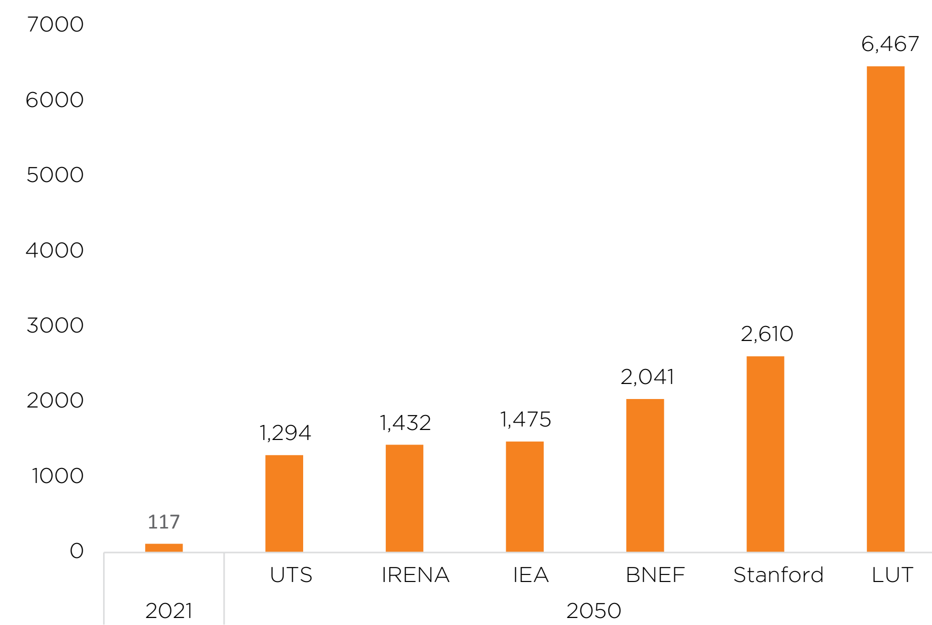
Source: LUT

[5] IEEE (2022): On the History and Future of 100% Renewable Energy Systems Research. Available at: https://ieeexplore.ieee.org/document/9837910

Despite the wide differences in the scenario results from the academia and other organisations, what appears clear from the analysis is that solar PV is going to play a major role in the future global energy system, with massive expansion in deployed capacities compared to today. According to the six scenarios analyzed, from the TW-level of cumulative capacity achieved in early 2022, the solar fleet is expected to increase between 12 to 63 times in the next three decades.

Using the Watt per capita indicator (Fig. 68), the scenarios taken into consideration anticipate between 1,294 and 6,467 W/c deployed at the global level by 2050, based on the assumption that the world will host 9.8 billion people by that year. Even in the most conservative scenarios, the global 1 kW/c mark will be surpassed by mid-century, a large growth from the 119 W/c reached in 2021. This also means that, even in low ambition scenarios, the world on average would surpass the country with the highest solar penetration per capita today, Australia, which stood at 1,049 W/c in 2021.

Fig 68. Solar PV Watt per capita scenarios in 2050

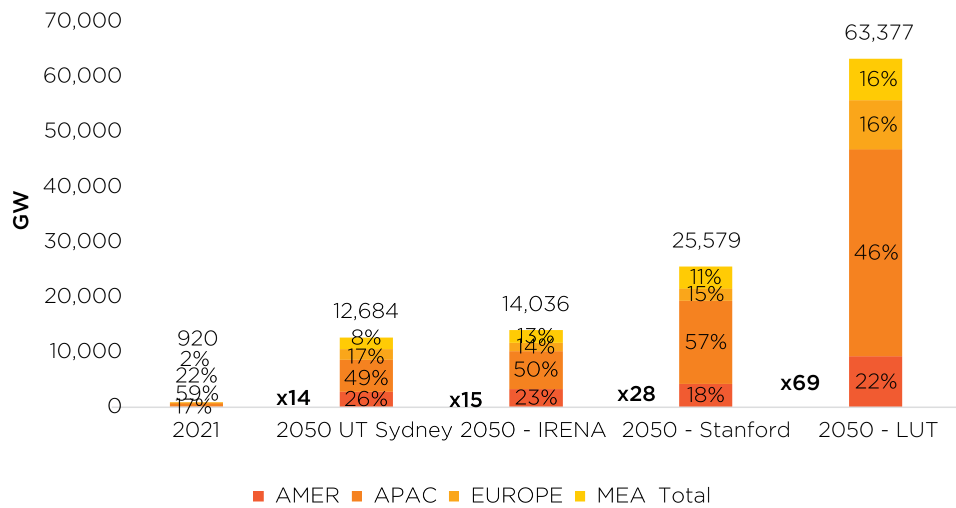


Sources: BNEF, IEA, IRENA, LUT, SPE, Stanford, UTS

Four of the six long-term scenarios considered – the UTS, IRENA, Stanford and LUT scenarios – provide regional distributions of global PV capacity deployment in 2050. Although the total PV installations differ significantly across the three scenarios, comparable trends in regional allocation of capacities can be observed.

Similarly to the dynamics already seen in the regional distributions in 2030, the APAC region loses significant shares of global installed capacity in the UTS and IRENA scenarios, decreasing from 58% in 2021 to 49-50%; in the Stanford and LUT scenario, the APAC share grows marginally to 59%.

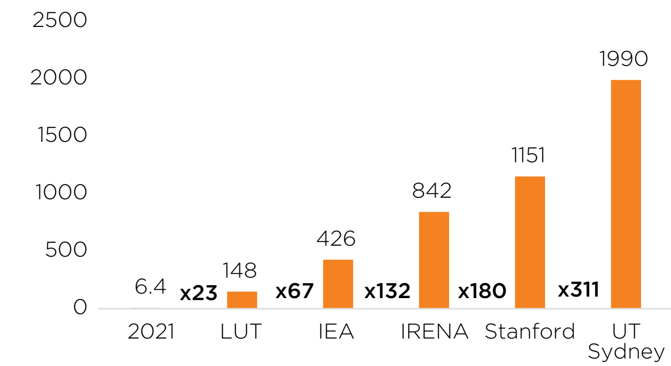
Fig 69. Regional distribution of total solar PV capacity in 2050



Source: IRENA, LUT, Stanford, UTS

Several of the long-term studies under consideration also provide capacity deployment figures for CSP in their scenarios. An overview is provided in figure 70. By 2050, CSP is expected to grow from the 6.4 GW installed in 2021 to between 148 GW (LUT) and 1,990 GW (UTS), with the IEA, IRENA and Stanford scenarios anticipating 426, 842 and 1,151 GW respectively. This corresponds to an increase in operating CSP capacity in a range between 23 and 311 times from 2021 levels. As discussed in the previous section, the UTS study relies strongly on CSP, decreasing the deployment share of PV. The choice of CSP over PV is based on the study's preference on technology diversification, different cost assumptions, and high expectations on decreasing costs of the technology. By contrast, the LUT study projects a lower expansion of CSP due to cost competitiveness vis-à-vis solar PV.

Fig 70. CSP - Total installed capacity scenarios 2050



Source: IEA, IRENA, LUT, Stanford, UTS

Challenges and Drivers to Solar Market Developments

5.1. Key Barriers

While solar development has followed an unprecedented growth path, the deployment of the technology is not free of any difficulties or barriers. This chapter goes through the main challenges that can arise and slow down the deployment of solar power, and renewables more generally. Further, it provides an overview of the regulatory instruments that can support solar growth and concludes with some reflections on the link between solar and geopolitical considerations.

5.1.1. Social awareness about the benefits of social PV

Removing all doubts about the benefits of solar PV is the first necessary step for it to be seriously considered by populations and policymakers. While the technology has reached a mature development point, there are still some myths debunking to do. This covers a wide range of topics, starting from the very capacity of solar technologies to replace fossil fuel and nuclear plants to generate enough electricity to cover the demand. But topics also cover: the financial cost of solar, the amount of space required by solar, the symbiose between solar plants and ecologically important areas, the production of electricity at night, the contribution of solar to reducing CO2 emissions, the availability of raw materials to assure the production capacity, and many more.

5.1.2. Fossil fuel subsidies

Subsidies to fossil fuels were initially allocated in order to maintain lower energy price and protect consumers. But today, they come at a greater societal cost. First and foremost, providing direct or indirect subsidies to fossil fuels reduces the pace of the energy transition. It lowers their price and does not incentivize their phase-out and replacement by renewables. It also widens the fiscal gap for many countries: first, as a financial cost, by offering money as subsidies; second, as a societal cost, since this brings negative externalities (air pollution leading to higher public health spending, water treatment, land damage) resulting from the use of fossil fuels. In other words, fossil fuel subsidies distort the efficient allocation of resources, which could go towards more sustainable solutions that increase social welfare. The International Monetary Funds (IMF) estimated that, in 2020, global fossil fuel subsidies amounted to $5.9 trillion or 6.8% of global GDP. It is also estimated that they could increase to around 7.4% of the global GDP in 2025 as the share of fuels consumption keeps increasing in emerging markets.

With electricity from renewable sources being cheaper than electricity from fossil fuels in many regions across the world today, the economic disadvantage of fossil fuel subsidies becomes apparent. This, however, also constitutes an opportunity to redirect investments and public spending to speed up the development of renewables.

5.1.3. Social acceptance

One of the main barriers to multi-Terawatt solar deployment is connected to the concept of resistance to change, which can translate into issues of social acceptance of solar technologies by local communities. In particular, the global energy transition intensifies the competition for land and its intended use, an issue that is especially challenging in countries with high population density. The problem of NIMBYism (Not In My Backyard opposition) is widespread across any large-scale project, and within the energy sector, is usually more related to other energy generation technologies. At the same time, as solar is poised to become the primary source of electricity in many countries across the world, it is important that the public acceptance towards this technology remains high. Already today, there are cases of local communities opposing solar projects in their vicinity, despite fundamentally supporting renewable energy deployment.

However, with solar being an energy technology that can be decentralised, a large part of deployment can take place on roofs, carports, public and commercial buildings, which do not require any land. Thanks to this versatility, solar is the technology with the highest acceptance ratio in opinion surveys. In addition, the integration of PV in architecture projects (so-called building integrated photovoltaics, BIPV) with solar tiles, roofs, windows, facades and balconies can further reduce its visual impacts. Still, because this requires a proactive participation of households and building owners, keeping social acceptance high is crucial and information about solar PV's characteristics and its benefits should be communicated effectively.

While rooftop solar is not subject to strong public acceptance challenges (except for instances of landmark buildings that can be addressed through BIPV), the deployment of ground-mounted solar projects can be of concern for local stakeholders, who want to ensure that social, environmental and economic considerations are taken into consideration, and that projects are beneficial to their communities under all these perspectives.

Space utilization concerns are high for ground-mounted solar projects, although research indicates that large solar parks have lower land use impacts than other energy generation technologies. When considering the whole project lifecycle, starting from material sourcing, product manufacturing to project construction, operation and maintenance, and finishing with end-of-life management, PV plants use relatively little land compared to other renewable generation sources, such as bioenergy. Highly efficient ground-mounted solar also uses less land than traditional energy sources like coal, who generate significant impacts from surface mining.

It is therefore extremely important to ensure that utility-scale solar parks are designed and built in the right manner, minimizing competition for land and creating additional value on top of renewable energy generation. For instance, technological solutions such as floating PV and Agri-PV make intelligent use of space and can reap double dividends for land owners -- even improving productivity, such as fewer evaporation in water reservoirs covered with solar panels or less need for irrigation of plants thanks to shading from agri-PV solar systems. Further, by implementing a few rules, solar parks can become habitats with a high degree of biodiversity and with positive impacts for the surrounding environment.

To address social acceptance challenges, it is essential that ground-mount solar development involves inclusive consultation processes with local stakeholders since the early project phases, with the objective of building the facility in harmony with nature and the local environment.

5.1.4. Labour availability

At the global level, IRENA estimates that out of the 12.7 million workers in the renewable energy sector, 4.3 million are employed in the solar industry. This large number of people working in solar is not a surprise, given that solar power is both the fastest growing power generation source and the most job-intensive renewable energy source. This provides a great opportunity for employment, since most of solar jobs are created at the deployment phase, and such jobs are local jobs. However, this can also become a vulnerability for the sector's further growth. As seen in chapter 4, solar deployment is poised to grow exponentially, and such growth needs to be accompanied by an increase in the solar workforce. Already today, the shortage of skilled workforce, especially at installation level, has been identified as a key bottleneck in several countries, especially those whose solar market has experienced a sudden steep growth.

Considering the pace at which solar employment must enlarge, it is essential to promote technical careers and education in solar jobs at all scales. In parallel, it will be key to monitor the quality of the jobs offered, and the ability to attract the to join the solar workforce that is underrepresented today.

5.1.5. Permitting

Long permitting procedures are identified as one of the major bottlenecks limiting the deployment of renewable projects. Currently, in Europe, the deployment of a ground-mount solar park can take up

to 6 years, which is incompatible with the pace of development needed to achieve the energy transition in time. The European Commission reported that administrative and grid issues make up about 46% of all identified barriers to renewable energy projects.

To address permitting challenges, it is necessary to establish clear guidelines to efficiently streamline permitting procedures. This relates, among others to optimizing administrative communication and processes, guidance and best practices, centralized provision of information, participation and acceptance measures, simpler procedures for small-scale and repowering projects, and clarified priority in administrative projects. To facilitate large-scale solar deployment, it is recommended to develop fast-track permitting processes and define priority areas benefitting from fast tracked procedures.

5.1.6. Grid constraints

Transitioning from an inflexible and centralized energy system to a system with a high penetration of variable and decentralized energy sources comes together with a number of technical challenges related to grids and the management of distributed power stations. To match the growing power demand stemming from the electrification of the heating and transport sector, grid capacity needs to be largely expanded. Yet, several countries are already facing grid congestion issues, which cause delays in the development, completion and entry into operation of solar projects.

Grid congestion refers to a situation in which the grid cannot integrate the electricity produced by power

plants, which therefore need to curtail their production. This condition can result in severe financial losses, as a number of developers experienced in Vietnam following the solar boom in 2019. Some densely populated areas with large electricity demand, such as the Netherlands, are also impacted by grid congestion as the construction time of new grid capacity is longer than the construction time necessary to develop new wind and solar farms.

The whole development of renewables is impacted by the lack of grid capacity, which also increases cost as demand for solar and wind projects is much higher than availability. It also leads to speculative behavior in tender procurement, as seen in the first ever negative auction price results in Portugal in April 2022. Power plant owners who bid negative prices will pay for each megawatt-hour put on the grid. Some developers evaluated that securing grid connection was sufficient enough to justify the negative price bid, as they might have the possibility to resell the secured grid connection at a higher price in the future or to hybridize the plant using a single connection point.

High grid costs are also impacting the business case for renewable development. This is the case in Denmark, where grid connection cost might skyrocket in the beginning of 2023, following a political decision. Several developers already announced that many projects in the pipeline will not be economically viable anymore.

In general, governments and national transmission systems operators need to increase the level of investments into grids to avoid those issues exacerbating. The IEA's World Energy Investment Report 2020 highlighted that investments into the grid have not significantly increased across the past years, a clear imbalance with the accelerated deployment of renewables. Not only grids need to be extended – both on the transmission and distribution level, but they also need to be modernized to allow a better oversight and controllability of the electricity markets. In parallel, this also calls for the development of flexibility solutions, such as electricity storage and demand-side response, to support grid stability.

5.2. Overview of supporting policies and regulatory frameworks

The development solar power experienced in the past two decades -- as illustrated in the previous sections of the report -- has been driven by effective support frameworks that enabled technological development and cost reduction through economies of scale. Policymakers around the world have a wide toolset of different policies and regulations that can be used to accelerate the deployment of solar technologies. This section outlines the most frequently used policy support instruments in order to achieve a faster energy transition.

The most widely used mechanism for accelerating the deployment of renewables have been **Feed-in tariffs (FIT)**. This consists of offering a long-term purchase contract to renewable energy producers for the renewable electricity they produce. The contract offers price certainty over a long period, which helps assessing the profitability of the investment. The contract typically ranges from 15-25 years, during which energy producers are offered an above-market price for every kilowatt-hour generated by their asset that reduces payback time over the duration of the contract. The price that is offered usually varies depending on the type of renewable source, the size and location of the project. The payments are typically decreasing over time for new contracts in

order to adjust for, and to encourage, technological improvement and cost reduction.

A feed-in tariff contract usually includes three key parameters: guaranteed access to the grid, the duration of the contract, and the price at which electricity will be sold. Determining the price compensation for the electricity produced is the paramount factor in designing a proper feed-in tariff policy. Different approaches can be used: based on the LCOE of the technology, based on an auction process, based on the “avoided-costs” from the generation technology, or offered as a fixed-price incentive. The compensation can also be linked to the spot market price of electricity and is then offered as a premium on top of the current price. In these conditions the policy is often referred to as a **Feed-in Premium**. The premium payment can either be constant or sliding (the premium then varies depending on the spot market conditions). While feed-in tariffs in the early days of the on-grid solar era were compensating all energy that was produced and fed into the grid, today feed-in tariffs are usually combined with self-consumption; the prosumer only feeds into the grid the power that is not consumed in-house. Different cases around the world have proven the effectiveness of feed-in policies. In Germany, the Renewable Energy Source Act from 2000 has been very successful in triggering renewable deployment and has been updated several times. More recently, the Vietnamese FIT case speaks for itself – a very high feed-in tariff attracted massive investments and propelled the country from having basically no solar PV in 2018, to the top 3 of largest installers in 2020.

FIT schemes can be set up in several different forms. One of these is through **Contracts for Difference** (CfDs), as in the case of the United Kingdom. CfDs set long-term energy contracts between energy generators and a dedicated government agency. Under CfDs, eligible generators are paid the difference between the strike price, which is a reference tariff reflecting the cost of investing in a specific energy technology, and the reference market price, which is a measure of the average wholesale electricity market price. CfDs offer the benefit of decreasing market volatility for both producers and consumers: generators have larger certainty and stability on the long-term revenues of their investments, while consumers are hedged against extremely high and volatile energy prices.

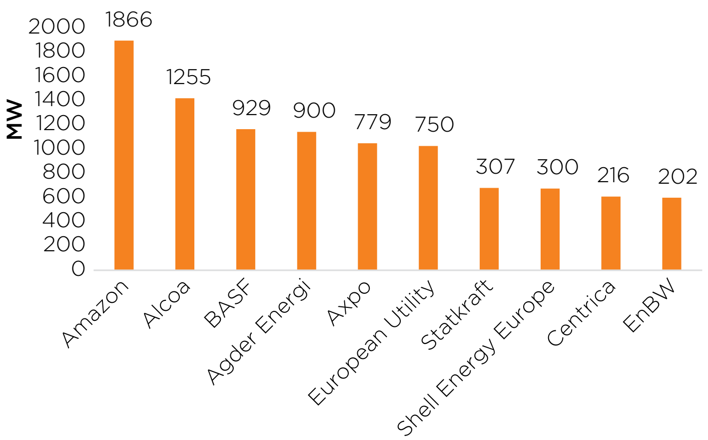
Net-metering policies are also part of the most widely tools to develop renewable energy sources. This policy helps non-dispatchable energy sources to benefit from the electricity they produce at a different time. The basic principle is that for every kWh that the asset puts on the grid, a kWh can be retrieved from the grid at a different period. This is particularly beneficial for small-scale solar PV systems that are not coupled with a battery. The PV system generates more electricity during the day, but for every kWh sent into the grid during the day, the household can make use of a kWh from the grid during the evening as it were self-consumed. Net-metering policies can be designed with different characteristics. One of the key parameters that policymakers can consider is the value of the credit: the amount of kWh sent to the grid and the amount of kWh that can be retrieved from the grid is not necessarily a 1-1 ratio. The rollover credit period can also change, with some net-metering policies not allowing the roll-over of credits from one month to another. Net-metering policies have successfully supported solar PV in different countries. In Europe, net-metering was implemented in countries like the Netherlands, which introduced the measure in 2004, helping the nation to develop a strong residential and commercial PV capacity in a country with limited land available. Poland also introduced net-metering in 2015. The attractiveness of this scheme increased to the point that a rush of installations took place in 2020 and 2021, just before the policy was turned into a net-billing (which is a variation of net-metering that takes into account the electricity price at the time of injection and ejection).

The United States were also pioneers in the adoption of net-metering as early as the 1980s in the states of Idaho and Arizona. Power utility companies have been critical of net-metering policies, as households do not pay for their full usage of the grid, and today’s generally high returns are even increasing as the gulf widens between decreasing solar cost and increasing grid power prices. Net-metering policies also do not incentivize at all the development of battery storage, which is considered an element for the energy transition to flexible renewable energy sources.

Feed-in tariffs and net-metering are part of policies that can help to develop self-consumption in countries where solar PV has not yet reached grid parity– meaning that the cost of solar PV electricity remains higher than electricity coming from the grid or as support tools of administrations to incentivize faster dissemination of solar to meet climate targets. In many regions where solar PV already has reached grid parity a flourishing number of unsubsidized projects can be found today, and the number is quickly increasing. Private actors and companies benefit from cheap and green electricity via corporate sourcing and **Power Purchase Agreement (PPA)**. A PPA is a contract signed between an energy buyer and a seller. The buyer is any private client looking to source its electricity from a renewable source, and the seller is the owner of a renewable power plant looking to sell its electricity. The two parties agree on the price and the amount of electricity which is or will be generated by the renewable asset. These are usually long-term contracts of around 10-20 years, but with increasing volatility and rising prices at energy markets, even shorter PPAs are being offered. Across the globe, the USA is the leading country in terms of PPAs contracted, followed by EMEA and APAC. In Europe, the market has been growing and added 4 GW in 2020 to reach a cumulative capacity of 12 GW in 2020. Historically, wind accounted for up to 90% of the contracted capacity, but solar PPAs are becoming more frequent as well, especially for on-site PPAs for commercial and industrial installations.

Consulting firm Pexapark estimates than in 2021, 141 deals were concluded in Europe representing a bit over 11 GW, a 58% CAGR from 2018. The largest country was Spain with 3.9 GW of capacity contracted, followed by Sweden with 1.9 GW and Germany with 0.8 GW. Though Spain is a clear leader, the spread between the largest and the second largest market keeps decreasing. In Italy, long and difficult permitting procedures prevent the country to increase its market volume. The largest buyers in Europe in 2021 were corporates, with Amazon leading the way with over 1.8 GW contracted in a single year (Fig. 71). Alcoa, the American steel manufacturer, and BASF, the German chemical industry, take spot #2 and #3 with 1.2 GW and 0.8 GW contracted. Looking at the breakdown per technology between 2019 and 2021, 10.9 GW of solar PPAs were contracted, 9.6 GW of onshore wind and 5.3 GW of offshore wind.

Fig 71. Top buyers (mixed) by contracted capacity, 2021



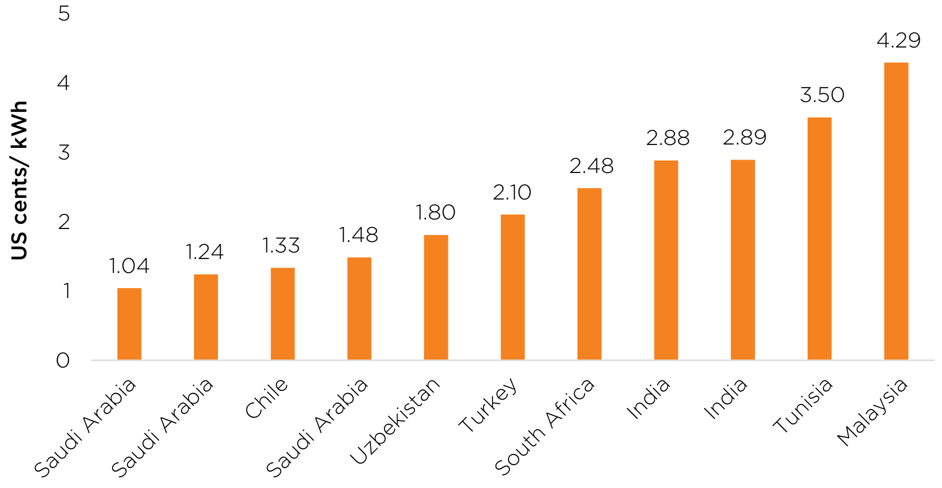
Source : PexaQuote

The price trend of PPAs has also increased due to the recent global energy development. Since the second half of 2020, price have increased 13.5% until April 2022. According to Bloombeg, the European solar PPA's price ranges from 37 €/MWh in Spain to 61.4 €/MWh in the UK, while European wind PPA ranges from 34.5 €/MWh in Sweden to 64 €/MWh in the UK.

At a larger scale, **auctions and tenders** are frequently held by countries to support the deployment of new generating capacities. Auctions and tenders are competitive bidding processes in which participants offer their bid to the auctioneer, which then awards the capacity to the best offer(s). Winners are awarded a remuneration of the energy provided at the price they bid for. The difference between auctions and tenders lies in the fact that a tender is a closed offer process in which competitors do not know the offer made by others. By contrast, an auction is an open-offer process in which bidders know the offer made by competitors and can adapt accordingly. Both processes allow a country to attract investments in renewables and to achieve their energy and climate ambition.

Throughout the years, solar auction prices have followed a decreasing trend. In 2019, the world saw the first solar auctions below 2 USD cents, and 2020 experienced the first results below 1.5 USD cent with 1.32 in Portugal and 1.35 in the UAE. The trend continued in 2021 with two record breaking auctions in Saudi Arabia: 1.04 USD cents for the 600 MW Al Shuaiba PV IP projects and 1.24 USD cents for the 1.5 GW Sudair solar complex (see Fig. 71). In a single year, the minimum bid price decreased by over 20%, once again affirming the ever-growing competitiveness of solar PV. Going still further, a first negative bid of 4.13 EUR cents per kWh was awarded in Portugal in 2022 for the development of a hybrid solar, wind and storage project.

Fig 71. SELECTION OF LOWEST SOLAR AUCTION BIDS AROUND THE WORLD IN 2021



Source: SPE

In terms of volume, several countries increased the amount of solar and wind power capacity that is offered in order to meet their increasing renewable energy demand. The German case is particularly striking as the auctioned volume grew from 2.1 GW in 2021 to 6 GW in 2022, on top of which an extra 1.5 GW PV capacity will be auctioned as a response to the energy crisis. In the same order, the United Kingdom is doubling the frequency at which it will hold renewable auctions, from biennial to an annual exercise starting from 2023.

Many countries also rely on Renewable Portfolio Standards (RPS) to increase the share of renewable electricity in their national mix. These policies require that a certain percentage of electricity sold by utilities is coming from renewable sources. South Korea has been relying on RPS since 2012 to diversify its electricity mix and the policy applies to power producer with an installed capacity over 500 MW. The obligatory renewable supply ratio started at 2% in 2012 and stands at 10% in 2022, growing 1% each year since 2016. In the same range of instruments, Guarantees of Origin (GOs) are certificates that assess the renewable nature of the electricity consumed by a customer. They are traded on a separated market and enable buyers to assert that the electricity they consume comes from renewable sources.

At a distributed level, an efficient way to develop rooftop solar is to introduce a rooftop mandate that requires buildings to include solar PV on their rooftops. The provisions of each mandate can largely vary depending on the types of building that are included and the time the mandate enters into force. As an example, as part of its REPowerEU plan, the European Union is currently building a framework for the introduction of a solar mandate for commercial and public buildings from 2027 and for new residential buildings from 2029. In Germany, the city of Hamburg introduced a rooftop mandate for all new buildings starting from 2023, while the federal state of Baden-Württemberg introduced a similar policy for new non-residential buildings from 2022. Similar provisions have been implemented in California in 2021.

At the installation levels, tax deductions, grants, and loans can be provided to help and incentives customers to acquire solar systems. A well-rounded tax deduction policy can be found in the United States, whose solar industry benefits from the Solar Investment Tax Credit (ITC). It allows customers to deduct 30% of the purchase and installation costs from their personal income taxes. Before the passing of the Inflation Reduction Act in 2022, the ITC was supposed to decrease to 26% in 2022, 22% in 2023 and terminate in 2024. Now, the rate has been increased to 30% and is prolonged until 2032, before decreasing to 26% in 2033, 22% in 2034 and 0% in 2035. In Italy, the Superbonus 110% has abruptly raised the residential solar installation levels. Under this scheme, homeowners are entitled to a 110% fiscal reduction based on the cost of upgrading their house with solar panels, heat pumps, insulations systems or others.

Finally, and more specifically targeted at off-grid solar, the Pay-As-You-Go (PAYGo) scheme involves the private sector and helps customers purchase larger systems. Companies offer credit to the consumer to purchase a solar system that is then reimbursed in regular settlement.

5.3. Geopolitics

The year 2022 highlighted the importance that geopolitics and international relations have in relation to solar and renewable energy. More specifically, there are two situations in which the political environment plays a leading role.

The first situation is when a country is dependent from another for the supply of solar PV's components. Today, China is leading the way in all stages of solar PV manufacturing, making all other nations dependent on it. Indeed, over the last decade, China invested over USD 50 billion in manufacturing capacities, progressively gaining a dominant position. According to the IEA, China's share in all steps of the manufacturing process of solar PV are as follow: 74% for polysilicon, 97% for wafers, 85% for cells and 75% for modules.

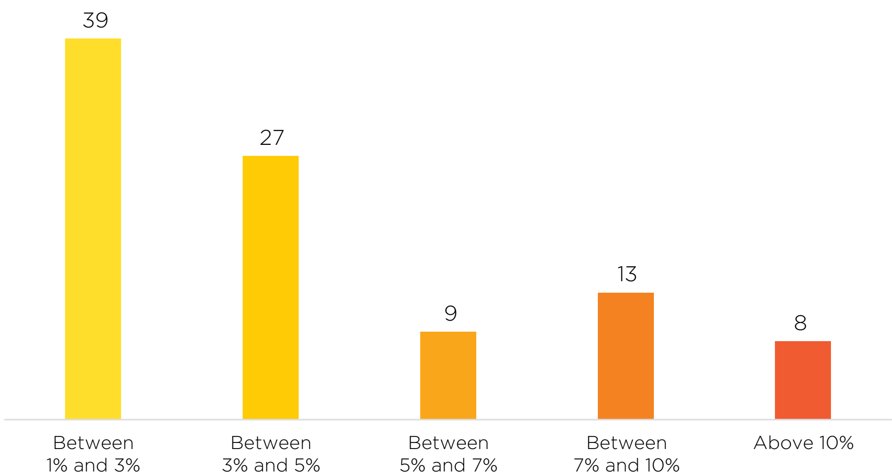
This concentration of the supply chain in a single country brings potential risks for the climate ambitions of other countries as a single disturbance can significantly reduce procurement of solar products. As a result, several countries are adopting policies to develop domestic manufacturing capacities. India launched the Production Linked Incentive (PLI) scheme aiming at boosting its PV production to 65 GW of module production, fully and partially integrated. The budget for the second part of the program was cleared in September 2022, when the government approved INR 195 billion – a fourfold increase from the first part. The United States Inflation Reduction Act (IRA) passed in August 2022 also attracts significant renewable investments in the country. The IRA invests USD 369 billion into the energy security of the country, including business incentives and tax credits for the manufacturing of solar module components.

The second situation in which geopolitics can modify the solar PV industry is when a country is reliant from another for the supply of its energy. This is the case of Europe's dependance towards Russian gas. Once Russia invaded Ukraine, it became an untrustworthy trade partner for Europe, which imposed sanctions on several economic sectors, including the energy trade flows. This new geopolitical reality forced the European Commission to diversify its energy supply routes and put together the REPowerEU plan which includes a strong acceleration of renewable and solar PV. The plan includes a new cumulative target of 750 GWDC for solar PV by 2030, a 56% increase from the previous Fit for 55 packages.

Conclusions (80)

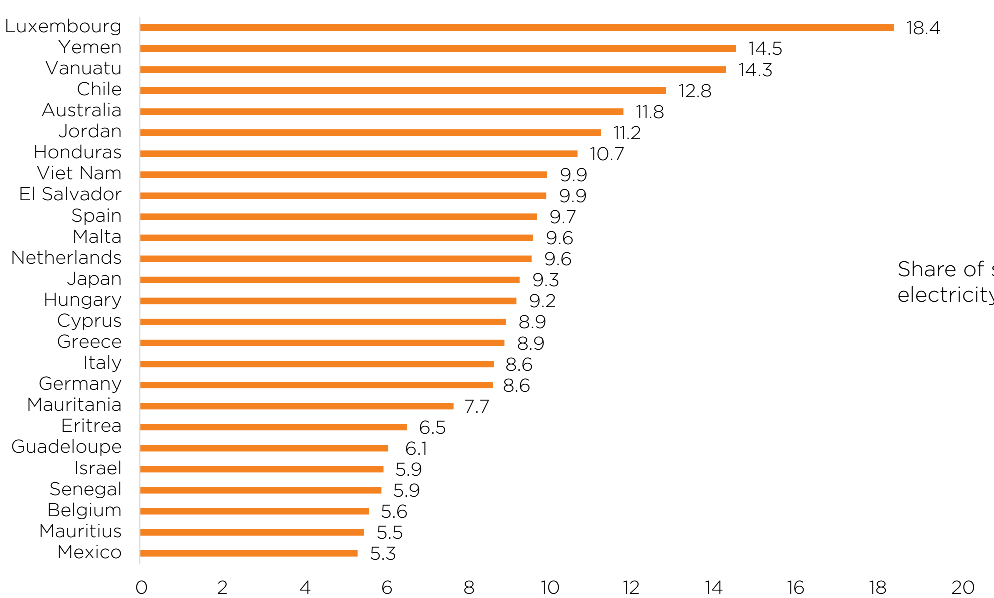
This section draws conclusions and a critical analysis on historical development of solar technologies as well as views on the future deployment. It also summarises the main recommendations for an adequate solar deployment.

10. Annexes



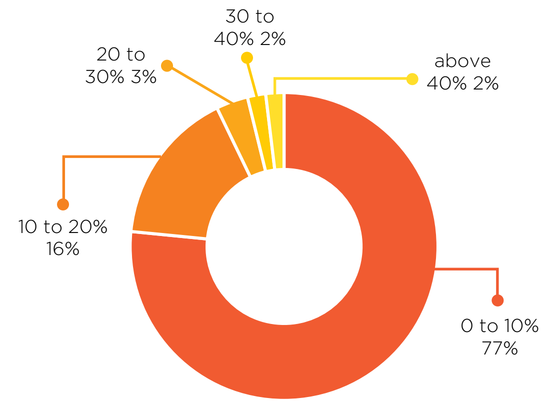
Number of countries above x% of solar PV in electricity mix

Source: Ember



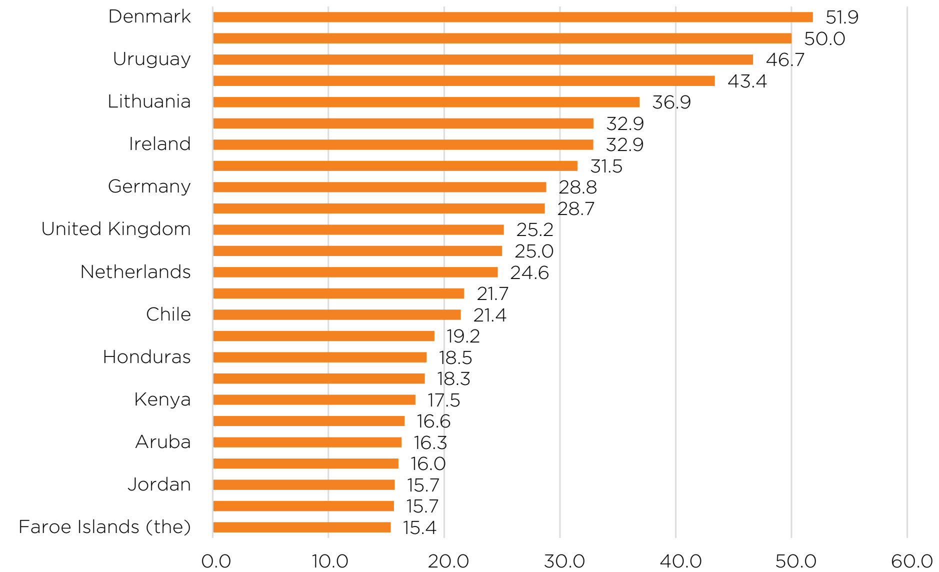
Share of solar PV in the electricity mix

Source: Ember



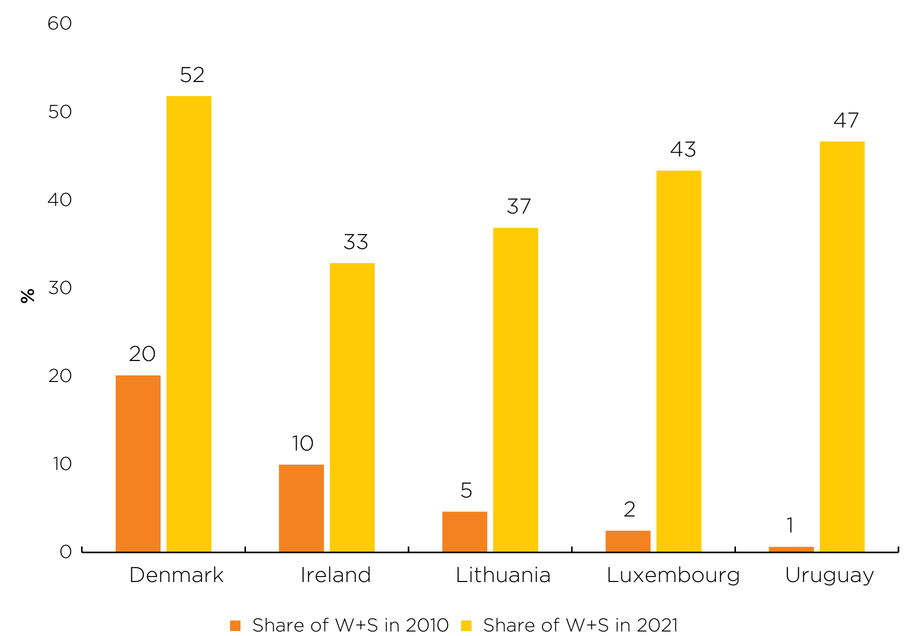
Number of countries per wind+solar share in the electricity mix

Source: Ember



Countries above 15% in electricity share from wind and solar

Source: Ember



Countries whose PV+Wind % share increase by at least 30% since 2010

Source: Ember

11. References

Breyer, C., Bogdanov, D., Khalili, S., Keiner, D. (2021). Solar Photovoltaics in 100% Renewable Energy Systems. In: Meyers, R.A. (eds) Encyclopedia of Sustainability Science and Technology. Springer, New York, NY. https://doi.org/10.1007/978-1-4939-2493-6_1071-1

Jacobson, MZ.,, von Krauland, AK., Coughlin, SJ., Dukas, E., Nelson, AJH., Palmer, FC., Rasumssen, KR. (2022). Low-cost solutions to global warming, air pollution, and energy insecurity for 145 countries,

Energy Environ. Sci.,15, 3343-3359.

Teske, S. (2019), Achieving the Paris Climate Agreement Goals, Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C, Springer Cham, https://doi.org/10.1007/978-3-030-05843-2.

BNEF (2021), New Energy Outlook 2021, BloombergNEF, London, https://about.bnef.com/new-energy-outlook/

IEA (2021a), Net Zero by 2050, International Energy Agency, Paris, https://www.iea.org/reports/net-zero-by-2050

IEA (2021b), World Energy Outlook 2021, International Energy Agency, Paris, https://www.iea.org/reports/world-energy-outlook-2021

IRENA (2022), Renewable Energy and Jobs Annual Review 2022, International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Sep/IRENA_Renewable_energy_and_jobs_2022.pdf

SPE (2022), Global Market Outlook for Solar Power 2022-2026, SolarPower Europe, Brussels, https://www.solarpowereurope.org/insights/market-outlooks/global-market-outlook-for-solar-power-2022

CONTACT US
International Solar Alliance Secretariat
Surya Bhawan, National Institute of Solar
Energy Campus Gwal Pahari,
Faridabad-Gurugram Road, Gurugram,
Haryana – 122003, India
Email: info@isolaralliance.org