INTERNATIONAL SOLAR ALLIANCE

WORLD SOLAR MARKET REPORT 2023

Foreword

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As the world moves away from fossil fuel-based energy generation, the importance of renewable energy has grown exponentially. Solar energy has stood out as the stellar performer in renewables, seeing a meteoric rise in a little over a decade. Solar's share in power sector generation has grown from 0.1% in 2010 to 5% in 2022. It is now the fastest-growing energy generation source and accounts for a significant share of new renewable generation capacity.

Solar photovoltaics (PV) has been leading that growth, with 226 GW installed in 2022, a sharp 38% growth from the year before. The global PV capacity has reached the terawatt scale through design, not merely by chance. Falling costs, increasing technology options, and supportive government programs and policies have engineered this growth. The emergence of innovative business models such as third-party ownership, community solar, flexible power purchase agreements, and integrated solutions with energy storage and microgrids have made solar energy furthermore accessible and affordable, benefiting a broader range of consumers and businesses.

Deploying off-grid solar and solar thermal also helps the technology meet demands that other renewable technologies cannot. However, their deployment rates fall short of PV deployment, as concentrated solar power added only 200 MW in 2022, while solar thermal installed 18% less capacity in 2022 than in 2021.

A variety of long-term and short-term scenarios for the future of solar capacities have been prepared by leading analysts, and studying these scenarios makes one thing clear: solar is set to grow. From 1 TW installed in 2022, the solar PV fleet might reach 10 TW by 2030 and up to 60 TW by 2050 in the most ambitious scenario.

While the growth figures for solar markets are undoubtedly promising, several vital 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. In 2022, the Asia-Pacific region accounted for 56% of total installed PV, while the Middle East and Africa region only represented 2%. 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 other 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 producing this Report for their contribution and support. I look forward to sharing the ISA World Solar Market Report 2023 with the global solar community.

Abbreviations

APAC	Asia Pacific
ALMM	Approved List of Models and Manufacturers
AMER	Americas
BIPV	Building Integrated Photovoltaic
BNEF	Bloomberg New Energy Finance
C&I	Commercial and Industrial
CAGR	Compound Annual Growth Rate
CCS	Carbon Capture and Storage
CSP	Concentrated Solar Power
CUF	Capacity Utilisation Factor
DISCOM	Distribution Company
DLR	German Aerospace Centre
DOE	Department of Energy
EC	European Commission
EGD	European Green Deal
EU	European Union
EUR	Euro
FiP	Feed-in Premium
FiT	Feed-in Tariff
GDIP	Green Deal Industrial Plan
GHG	Greenhouse gas
GMO	Global Market Outlook
Gt	Gigaton
GW	Giga Watt
GWth	Giga Watt Thermal
IEA	International Energy Agency
IEA-SHC	International Energy Agency's Solar Heating & Cooling Program
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPH	Industrial Process Heat
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency

ISA	International Solar Alliance
ITC	Investment Tax Credit
LUT	Lappeenranta-Lahti University of Technology
MEA	Middle East and Africa
MENA	Middle East and Northen Africa
MW	Mega Watt
NIMBY	Not In My Backyard
NZE	Net Zero Emission
NZIA	Net Zero Industrial Act
PLI	Production Linked Incentive
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PTC	Production Tax Credit
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
RED	Renewable Energy Directive
REZ	Renewable Energy Zone
RPS	Renewable Portfolio Standard
S&P Global	S&P Global Commodity Insight
SDG	Sustainable Development Goals
SHS	Solar Home System
SPE	SolarPower Europe
TW	Tera Watt
UAE	United Arab Emirates
UFLPA	Uyghur Forced Labor Protection Act
UK	United Kingdom
USA	United States of America
USD	United States Dollar
UTS	University of Technology Sydney
W/c	Watt per capita
WEO	World Energy Outlook
WRO	Withhold Release Order
YoY	Year on Year


Period: 2023
Marketing
Sales Statistics
Statistic
Analysis
65%
75%
90%
JULY
A
FILLTER
B
FILLTER
C
FILLTER
JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DIC
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Executive Summary

Climate change is undeniably one of the most pressing global challenges of our time. The alarming rate at which our planet is warming, driven primarily by human activities such as the burning of fossil fuels, deforestation, and industrial processes, necessitates immediate and substantial action.

The scientific consensus is clear: our world is on the precipice of a climate crisis that poses severe and potentially irreversible consequences for ecosystems, economies, and societies.

The urgency to tackle climate change cannot be overstated. Rising temperatures, melting ice caps, extreme weather events, and shifting weather patterns are already causing havoc across the globe. From the increased frequency of devastating wildfires and hurricanes to the displacement of vulnerable communities due to rising sea levels, the consequences of inaction are dire. Furthermore, the impacts of climate change extend beyond environmental concerns. The economic and societal implications are profound. Global food security, public health, and international security are all at risk. It is, therefore, paramount that we take swift, comprehensive, and transformative measures to mitigate and adapt to these changes.

One of the primary sectors that can contribute significantly to the global effort in combating climate change is the power sector. In the year 2022, the global CO_2 emissions of the sector were at its highest with 14.65 Gt CO_2 according the International Energy Agency (IEA), followed by industry emissions (9.15 Gt CO_2), Transport (7.98 Gt CO_2) and Buildings (2.97 GT CO_2). The reason for this substantial share of greenhouse gas (GHG) emissions is because electricity is still primarily generated through the combustion of coal and natural gas. In 2022, the electricity and heat generation sector also observed the highest increase in emission experiencing a 1.8% increase equivalent to 261 million tons.

It is notably coal-fired electricity and heat generation which contributed substantially to this global emissions surge, showing a growth of 2.1%, adding 224 million tons to the total, with emerging economies in Asia taking the lead. Transitioning from traditional, carbon-intensive power generation methods to renewable energy sources is a pivotal step in addressing this challenge. And it is thanks to the substantial growth of renewable energy sources that the world was able to limit the rebound of coal-generated emissions in 2022. Renewables accounted for 90% of the increase in global electricity generation last year. Both solar photovoltaic (PV) and wind power saw a remarkable rise of approximately 275 terawatt-hours (TWh) each, setting a new annual record.

The transition towards renewable is therefore a pivotal step in addressing the urgent challenge of rising GHG emissions and climate change. Among the diverse available renewable energy sources, solar energy stands out as a technology with immense potential to revolutionize the global energy landscape. Solar systems harness the abundant energy provided by the sun, converting it into clean electricity and heat with minimal environmental impact. It offers a range of advantages that make solar a compelling choice for a sustainable and low-carbon energy future. First and foremost, it is an abundant and sustainable source of energy. The sun provides an almost infinite source of energy. It is estimated that in just one hour, the Earth receives enough solar energy to power global electricity consumption for a year. This staggering potential underscores the capacity of solar PV energy to meet our energy needs while minimizing our impact on the environment. Then, solar systems also boast a crucial environmental benefit: zero emissions. They generate electricity without emitting greenhouse gases or other pollutants. This makes them a key component of decarbonizing the power sector, essential in mitigating climate change and reducing air pollution. The emissions of solar PV are only generated in the manufacturing phase and remain marginal. The median lifecycle emissions of solar PV ranges from 41-48 gCO_2eq/kWh, comparing to 820 gCO_2eq/kWh for coal, and 490 gCO_2eq/kWh for natural gas (Intergovernmental Panel on Climate Change)[1].

1 Schlömer S., T. Bruckner, L. Fulton, E. Hertwich, A. McKinnon, D. Perczyk, J. Roy, R. Schaeffer, R. Sims, P. Smith, and R. Wiser, 2014: Annex III: Technology-specific cost and performance parameters. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Scalability is another advantage of solar installations. They can range from small residential units to massive utility-scale projects, making them adaptable to various needs and geographic locations. Whether for a single household or an entire city, solar PV technology can be tailored to fit the energy demands of the specific environment.

Furthermore, the growth of the solar industry has brought significant economic benefits. It has created jobs and economic opportunities, making it an engine for local and global economic growth. This growth is not only good for the environment but also for employment and the overall economy, making solar energy a win-win solution. In its latest Annual Review 2023, the International Renewable Energy Agency (IRENA) estimated that 4.9 millions workers were employed in the solar PV industry in 2022, representing more than a third of all jobs in renewable energy, and is the fastest growing energy sector. In addition, women hold 40% of the full-time positions in the solar PV workforce, surpassing any of the other renewable energy sectors and nearly doubling the percentage seen in the oil and gas industry.

Solar systems also offer a degree of energy independence, reducing dependency on fossil fuels and enhancing energy security. By harnessing the power of the sun, individuals, communities, and nations can reduce their reliance on imported fossil fuels, insulating themselves from volatile energy markets and enhancing their overall resilience. The levelized cost of energy of Solar PV, as of 2022, costs as low as 24 $/MWh, making it cheaper than coal and natural gas electricity production, which lowest cost stood at 69 and 115 $/MWh, respectively[2]. Over the last decade, solar PV

2 Lazard's Levelized Cost Of Energy Analysis – Version 16.0

module costs have dropped by 90%, while fossil fuel prices have mainly stagnated, or fluctuated upward. These numbers highlight that not only is solar energy environmentally responsible, but it's also a financially wise choice.

In conclusion, solar PV energy presents a compelling solution to address the pressing challenge of climate change. Its abundance, sustainability, zero emissions, scalability, economic benefits, and energy independence make it a versatile and effective means to reduce greenhouse gas emissions, protect our planet, and build a more resilient and sustainable future for generations to come. Transitioning to solar PV energy is not only a sound environmental choice but also a strategic and economically beneficial one.

The urgency of tackling climate change demands that we take immediate and ambitious steps to transition to clean and sustainable energy sources. This report will delve deeper into the benefits, challenges, and potential of solar PV energy, providing insights and recommendations to drive the transformation of our energy systems. Through a dedicated focus on solar energy, we aim to empower policymakers, industry stakeholders, and individuals to make informed decisions that contribute to the collective goal of combating climate change and securing a brighter and more sustainable future for generations to come.

Chapter 1 of the report briefly presents the methodology used in the writing of this report.

Chapter 2 provides a holistic approach to the global energy transition and the role that solar energy plays in it. Between 1965 and 2022, the amount of energy consumed globally has quadrupled.

Throughout this time, the portion of renewable energy in the total energy used has slowly grown from 6.5% to 13.6%. The growth in renewable energy has mainly come from non-hydropower technologies, specifically solar, wind, and biomass energy, which were still below 1% around the year 2000 and grew to account for 6.8% of the total energy consumed in 2022. Looking at electricity generation more specifically, coal stands as the foremost contributor, constituting 36% of the total electricity generated in 2022. Following is natural gas (23%), hydropower (15%), and nuclear (9%). Finally, wind, solar, and biomass collectively generated 4,204 TWh in 2022, constituting 7%, 5%, and 3% of the global electricity generation, respectively.

Chapter 3 focuses on the historical development of various solar technologies. The solar PV market displayed an impressive compound annual growth rate (CAGR) of 37% since 2000, with an annual market size reaching 226 GW in 2022, a 38% increase from 2021. By the end of 2022, the total capacity reached 1,143 GW, marking a 25% increase from the 917 GW recorded in 2021. In regional development, the Asia-Pacific (APAC) region led with 59% of the annual installed capacity in 2022, predominantly driven by China, which accounted for 42% of the global installed capacity. Europe maintained its position as the second-largest region, installing 47.1 GW in 2022, representing a 21% market share. The Americas, third region, installed 38 GW, up from 32 GW in 2021. On a lesser scale, the market in the Middle East and Africa (MEA) accomplished an installation of 7.1 GW, a record-year for the region accounting for a 3% share of the global market. Israel has taken the lead as the Middle East's primary solar market by adding slightly over 1 GW of new capacity. Meanwhile, in Africa, South Africa has maintained its prominent stance by installing 1.3 GW of solar capacity in 2022. Within the region, the Middle East and Northen Africa (MENA) remains larger than the Sub-Saharan countries where on-grid PV expansion struggles to take off outside of South Africa. Additionally, the chapter discusses installed watt per capita and solar PV grid penetration, noting Australia and the Netherlands as two countries exceeding 1 kW of solar PV installed per capita and an increase in global watt per capita from 119 in 2021 to 144 in 2022. In terms of grid penetration, renewable energy constituted 29.6% of electricity generation, with solar PV making up 4.6%. The chapter also analyzes the annual development of Concentrated Solar Power (CSP) and Solar Thermal Heating, showing installations of 200 MW and 19 GWth, respectively.

Chapter 4 presents global solar deployment scenarios for 2025, 2030, and 2050. The analysis considered projections from various

leading solar market experts, including research from organizations such as the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), energy analysts Bloomberg New Energy Finance (BNEF), and S&P Global Commodity Insight (S&P Global), in addition to insights from the European PV industry association SolarPower Europe (SPE) and long-term energy modeling research groups from academia. Averaging the forecasts from these institutions anticipates an annual solar PV market of 493 GW in 2025, more than doubling from 2022 levels, with scenario variations ranging from 462 GW to 521 GW.

The cumulative total operating PV capacity is projected to exceed 2 TW by 2025 in all scenarios, reaching ranges of 2,381 to 2,622 GW, compared to 1.1 TW in 2022. Regional breakdowns are expected to remain relatively stable, with the Asia-Pacific (APAC) holding 58% of total installed PV. In 2030, total installed capacity for solar PV varies from 5.1 TW to 10.2 TW, with renewable energy's share in electricity generation ranging from 59% to 89%. CSP capacity also displays divergence in forecasts, ranging from 6.6 GW in 2022 to 73 GW, and up to 474 GW in more optimistic scenarios. By 2050, total solar PV installed capacity is projected to reach 12.6

TW and potentially 63.4 TW, though most estimates fall within 17-25 TW. The wide range of estimations can be attributed to several diverse factors, including the level of ambition in each of these different scenarios, the methodology utilised, the scope and the type of model that was applied, the degree of technology diversification and cost assumptions, and other independent parameters that can exert a significant impact on the scenario results.

Finally, **Chapter 5** offers an overview of key obstacles that may hinder the adoption of solar PV and renewables. The main obstacles highlighted include societal acceptance of solar technologies, continued fossil fuel subsidies, labor availability, administrative and permitting challenges, renewable power curtailment, underdeveloped energy storage, and the geographic concentration of solar manufacturing. The chapter also evaluates three supportive initiatives promoting solar technology development: the Inflation Reduction Act (IRA) in the United States, Production Linked Incentives (PLI) in India, and the European Green Deal in the European Union.


Total Orders
13,678
Total Sales
11,892
Total Profit
$6,789
5.67%
10.75%
35.7 %
16.8%
23.6%
ANALYSIS 2
ANALYSIS 3

Approach and Methodology of the report

The information related to solar energy included in this report is derived from various accessible sources, which occasionally exhibit notable disparities.

Given the complexity of accurately gauging solar capacities deployed across different countries and regions worldwide, analysts and intergovernmental organizations employ diverse methodologies and sources to compute the global progression of solar energy. When it comes to historical data, the approach taken in this report involves calculating the simple average of prominent available sources. This methodology is applied to all figures that present historical data and reference multiple sources. Conversely, projected scenarios are presented at the individual organization level to capture the varying levels of ambition inherent in each scenario.

The data relating to segmentation and off-grid solar energy also manifests inconsistencies due to different methodologies. The precise demarcation between residential, commercial, industrial, and utility-scale solar energy fluctuates according to the sources, with some even categorizing on-grid, off-grid, and solar power use for hydrogen together. Wherever feasible, adjustments have been made to the data to facilitate meaningful comparisons.

It should be noted that the data utilized in this report is presented to the best of the authors' knowledge, drawing from publicly available information and exchanges with sources through bilateral communications.

Global Energy Transition is on the March

2.1. Renewable rush: swift growth but subtle impact in the energy landscape

In recent decades, there has been a noticeable and increasingly rapid shift in the way we use energy. The demand for energy across the world has been steadily increasing over a long period, and only in recent years have we seen a significant rise in the use of renewable energy sources.

Between 1965 and 2022, the amount of energy consumed globally has quadrupled (as shown in Figure 1). Throughout this time, the portion of renewable energy in the total energy used has slowly grown from 6.5% to 13.6%.

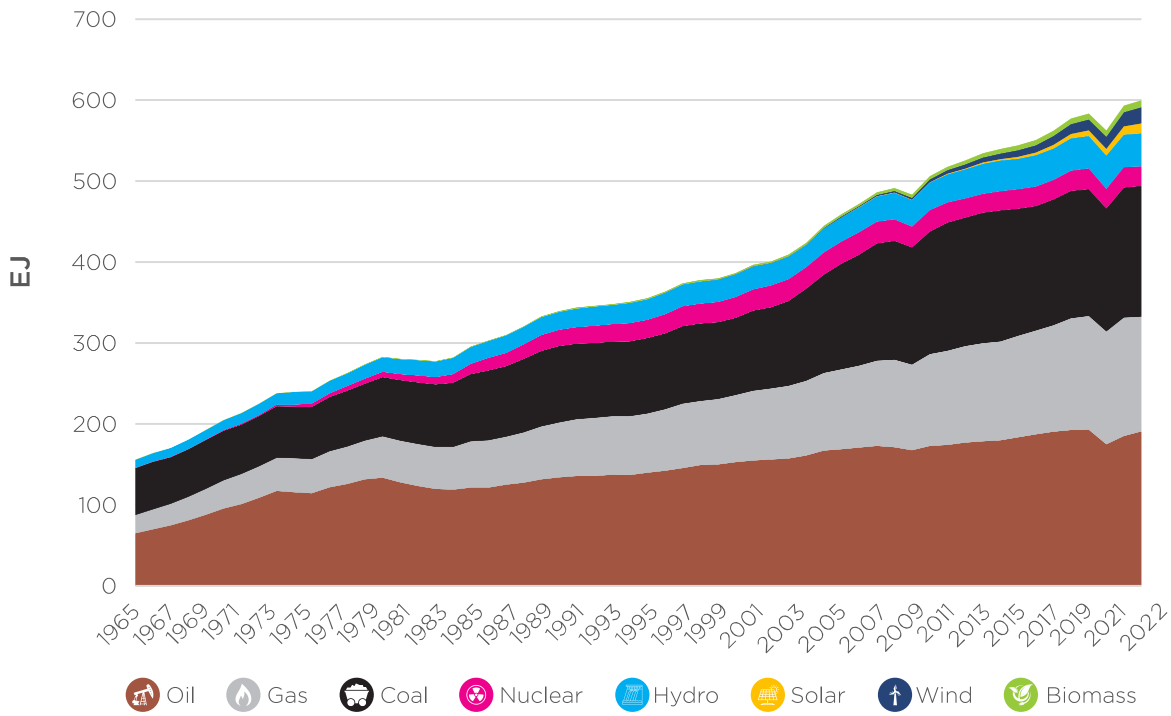


Figure 1: Global primary energy consumption by fuels, 1965-2022

Source: Energy Institute

When we take a closer look at the various technologies used for renewable energy, it becomes clear that the share of hydropower, which made up almost all of the renewable energy capacity in the early years, has remained quite stable at around 6-7%. The growth in renewable energy has mainly come from non-hydropower technologies, specifically solar, wind, and biomass energy. These renewable energy sources were almost non-existent in the 1960s and were still below 1% around the year 2000. However, by 2022, they had grown to account for 6.8% of the total energy consumed (see Fig. 2).

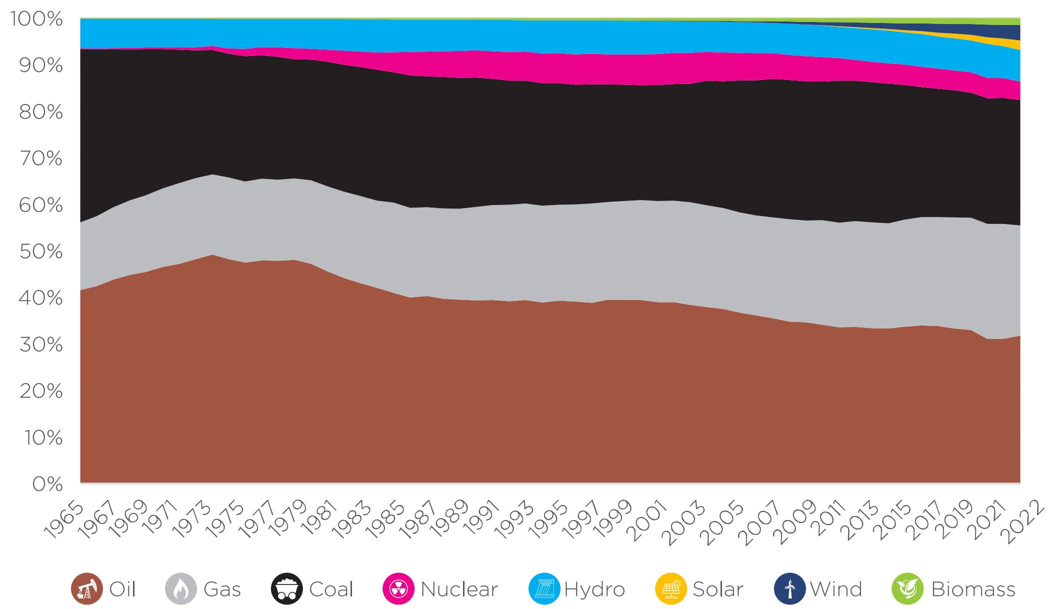


Figure 2: Share of global primary energy consumption by fuels, 1965-2022
Source: Energy Institute

At the same time, the proportions of conventional energy sources have changed, but their relative rankings have stayed the same. Oil, which was the largest energy source in 1965 with a 41.6% share, still contributes the most with a 31.8% share. Coal, the second-largest source, has seen its share decrease from 37.3% to 26.9%. Gas, on the other hand, has increased its share from 14.6% in 1965 to 23.7% in 2022, but it has retained its third position. The combined share of fossil fuels in the total primary energy used has dropped by 11% points, from 93.4% in 1965 to 82.4% in 2022. Throughout those 6 decades, the fastest reduction in fossil use happened in 2020, where it decline by 1.2% as a consequence of the COVID-19 pandemic. This decline is due to the increase in renewable energy sources and nuclear energy, which accounted for 4.3% in 2021, down by 2.4% points from its peak in 2001.

However, one need to keep in mind that renewable energy sources like solar and wind are primarily used in the electricity generation sector, and do not have a strong influence in primary energy consumption yet. Renewables are commonly integrated into power grids to provide a portion of the electricity consumed by homes, businesses, and various industries. Additionally, these renewable energy sources are increasingly being used in off-grid and remote areas where traditional energy infrastructure might be lacking or expensive to implement. This includes applications like providing power for remote communities, water pumping, telecommunications, and more.

The global electricity consumption has followed a trajectory similar to that of total global energy consumption. From under 10,000 TWh in 1985, the world's total electricity usage has surged to nearly 29,000 TWh in 2022, marking a remarkable growth of 194%. As illustrated in figure 3, this increase in electricity generation has largely been achieved through the utilisation of fossil fuels, primarily coal and natural gas.

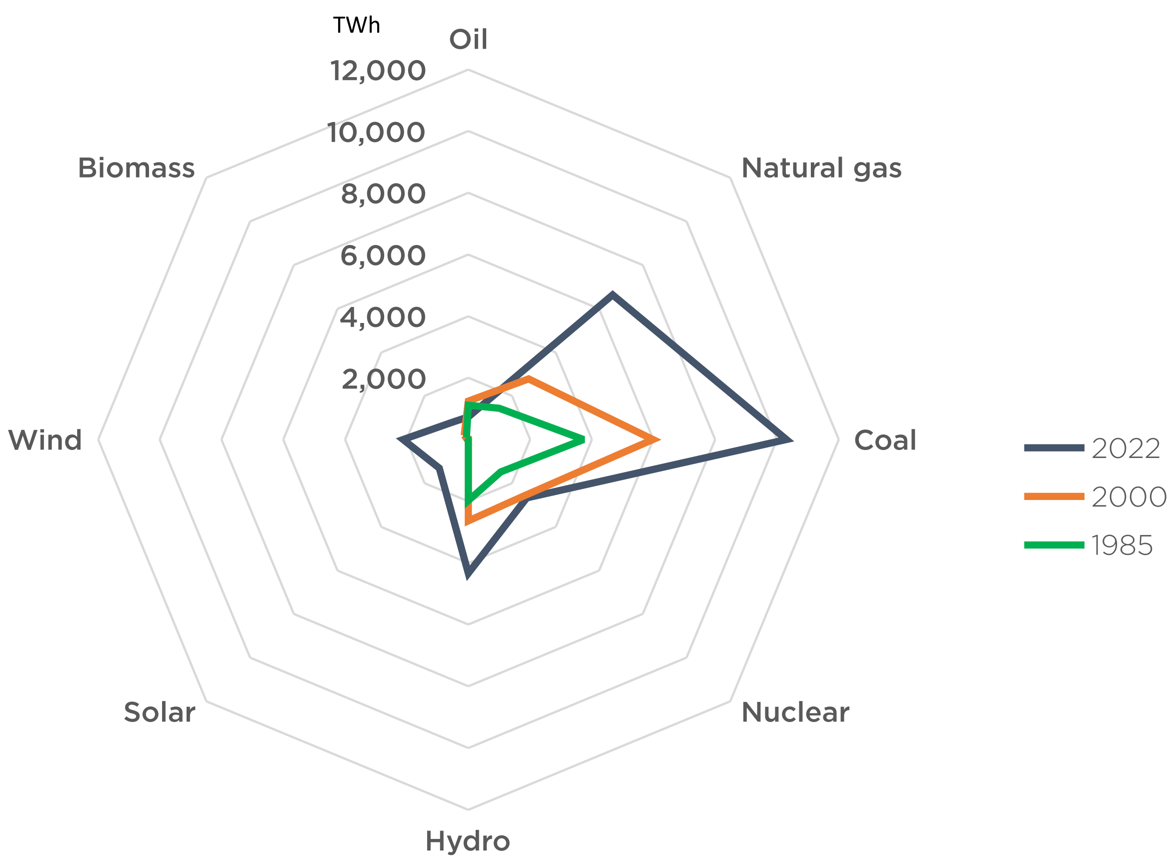


Figure 3: Shift in the global power generation from 1985 to 2022

Source - Energy Institute

As of 2022, traditional generation sources continue to hold a significant share in the global electricity production landscape (see fig 4). Coal stands as the foremost contributor to electricity generation, producing 10,204 TWh in 2022, constituting 36% of the total electricity generated during that year – an increment of 118 TWh from 2021. Following is natural gas, generating 6,462 TWh of electricity, accounting for 23% of global electricity and a 38 TWh increase compared to the previous year. The third most prominent electricity source in 2022 is a renewable one: hydropower, generating 4,300 TWh, equivalent to 15% of the annual electricity generation and an augmentation of 56 TWh from 2021. On the other hand, nuclear energy experienced a decline of 124 TWh in 2022, bringing its contribution down to 2,679 TWh. Lastly, wind, solar, and biomass collectively generated 4,204 TWh in 2022, constituting 7%, 5%, and 3% of the global electricity generation, respectively.

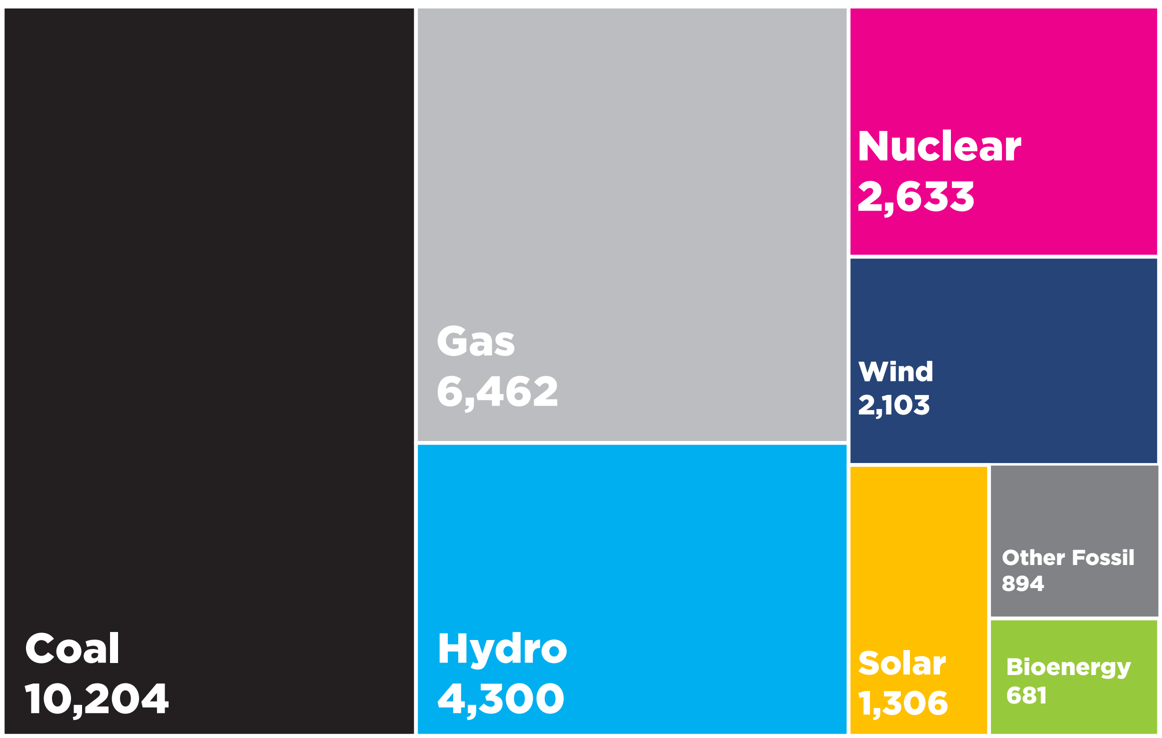


Figure 4: Electricity generation by source in TWh, 2022
Source - Ember

When we examine the rate at which power technologies have been adopted, it becomes essential to recognise the transformative impact of wind and solar technologies in the last two decades. Figure 5 visually represents the growth of different technologies to the global electricity generation since 2000. Notably, fossil and hydro technologies exhibit a more consistent growth trajectory compared to wind and solar, which have maintained a rapid pace of deployment, with solar energy leading the way. In contrast, nuclear energy, which experienced significant growth during the 1970s and 1980s, has plateaued since that period. This indicates that the trend toward renewable is definitely on march, still, their current small share in global electricity generation indicates the need to an acceleration for the world to keep on track with a 1.5°C trajectory.

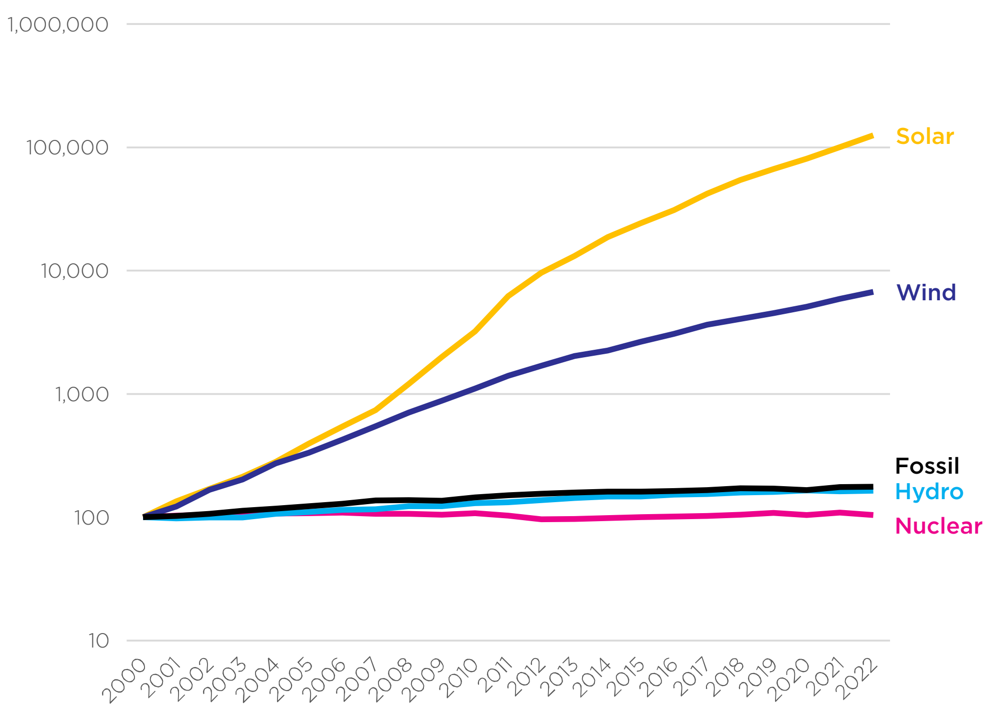


Figure 5: Growth in electricity generation by source (year 2000 = 100)

Source - Energy Institute

Looking more specifically at solar deployment, it appears that, until recent times, it was essentially absent from the global energy production landscape. However, within the realm of the power sector itself, solar's presence has seen a swifter expansion. It has surged from a minuscule 0.1% share in 2010 to an impressive 4.6% in 2022.

While this proportion might still seem limited, these advancements should be appreciated in context. In 2022, solar's total share witnessed an absolute increase of 0.9% compared to the preceding year, once again affirming its standing as the fastest-growing source of power generation. Notably, of the over 350 GW of new renewable power generation capacity established in 2022, solar PV alone contributed to two-third of it. Looking forward, it's anticipated that solar PV will account for half of the entire generation capacity in the long term. The upcoming sections of this report will delve deeper into the development of solar technologies across the globe to understand the dynamics of its expansion across the globe.

Global Solar Market Overview

Over the past two decades, solar technologies have undergone rapid and remarkable growth, with solar photovoltaics (PV) leading this expansion. Around the early 2000s, global installed PV capacity was merely 1,600 megawatts MW.

The momentum picked up with the launch of feed-in tariff programs in countries like Japan and Germany. Initially, PV technology gained traction on rooftops, mainly in residential areas, driven by its versatility. Later, the large-scale solar PV power plant market emerged due to cost reductions and support initiatives. By 2008, installed PV capacity surpassed 10 GW, reaching 100 GW in 2013, and remarkably, 500 GW in 2018. As of spring 2022, the milestone of 1000 GW (1 terawatt TW) was reached.

Today, most solar PV capacity is grid-connected. Off-grid PV systems, like small solar home setups and mini grids, comprise less than 1% of total PV capacity, around 6 GW in cumulative capacity. With over 700 million people lacking stable electricity access, the off-grid PV market remains substantial, serving nearly 500 million users globally in 2022. Solar PV has emerged as a crucial instrument in securing access to clean, reliable and affordable, aligning with the Sustainable Development Goals. Its significance has been further underscored due to a recent rise in the number of individuals lacking access to electricity, which saw an increase of almost 20 million in 2022 – the first increase in two decades.

Solar thermal energy, another significant solar technology, employs sunlight's heat for heating and cooling in residential, commercial, and industrial sectors. By 2010, the solar thermal industry had installed 245 GWth (thermal gigawatt), growing at a slower pace than PV. Its growth over the past decade brought its cumulative capacity to 542 GWth by the end of 2022. Additionally, solar thermal energy can also generate electricity via concentrated solar power (CSP); however, at the moment, this approach is notably less utilised compared to the solar photovoltaic and solar thermal heating.

3.1. Solar PV installations

3.1.1. Annual and cumulative deployment

Solar PV technology began to gain traction in the early 2000s, sparked by the introduction of initial support programs for residential PV systems in a handful of pioneering nations. Fast-forwarding two decades, the solar PV landscape has undergone a profound transformation. Presently, solar PV systems are being implemented across nearly every country worldwide, universally recognized as a cornerstone of the renewable energy shift. The annual on-grid installations of solar PV reached the GW milestone in 2004, crossed 10 GW in 2010, surged to 100 GW in 2018, and reached a remarkable 226 GW in 2022. With an impressive compound annual growth rate (CAGR) of 37% since 2000, solar PV has firmly established itself as the swiftest-growing energy technology, radiating the brightest prospects. The market's dimensions in 2022 marks an 38% growth from 2021, an impressive acceleration from the 13%, 24%, and 17% in the previous years, triggered by the global energy crisis and the growing demand for clean and affordable electricity. It also represents an astounding 679% expansion compared to a decade earlier (see fig 6).

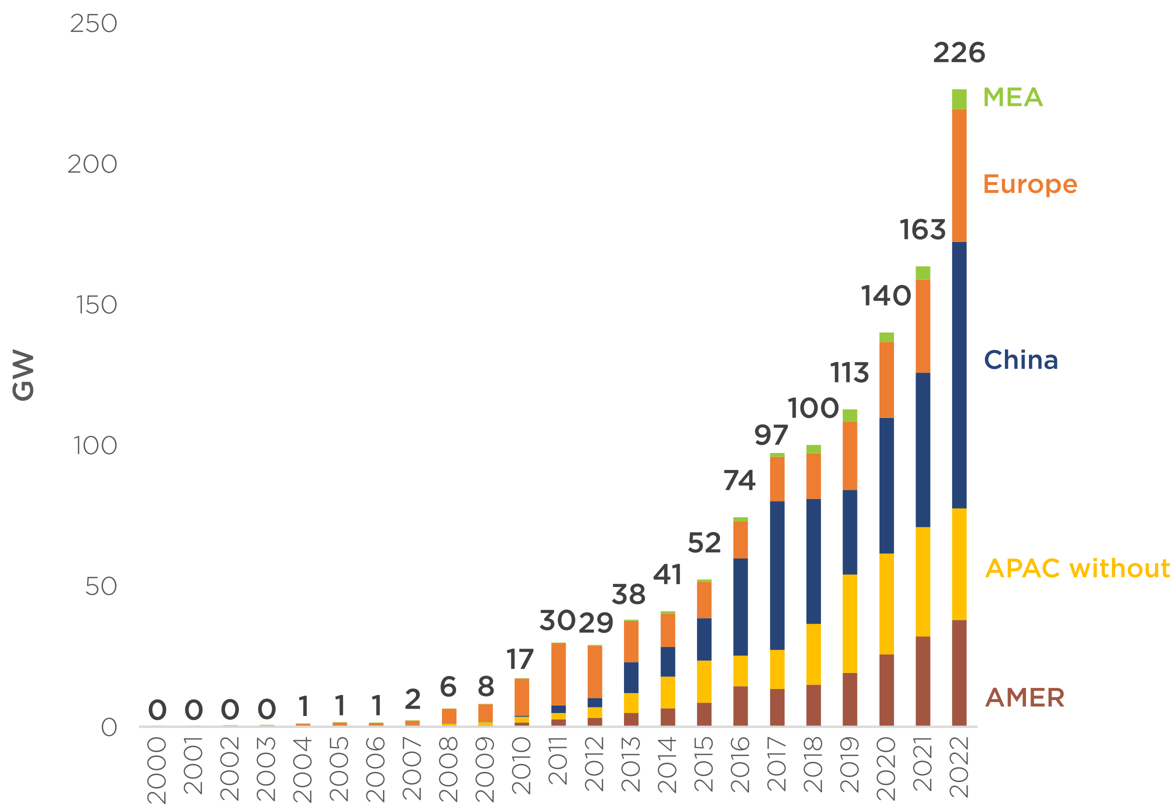


Figure 6: Annual global solar PV market deployment 2000-2022
Sources: SPE, IRENA, IEA, BNEF, S&P Global

The narrative echoes a similar pattern when we shift our focus to cumulative solar PV capacity (see Fig 7). Since the inception of the world's first grid-connected solar panel, this capacity has aggregated to 1,143 GW by the end of 2022. This represents a 25% increase from the preceding year's 917 GW recorded in 2021. Looking back, the collective solar PV fleet has burgeoned nearly 600-fold since the year 2000, and it has undergone an astonishing 1,070% surge compared to the overall capacity established by 2012, when a cumulative total of 98 GW of solar PV was commissioned.

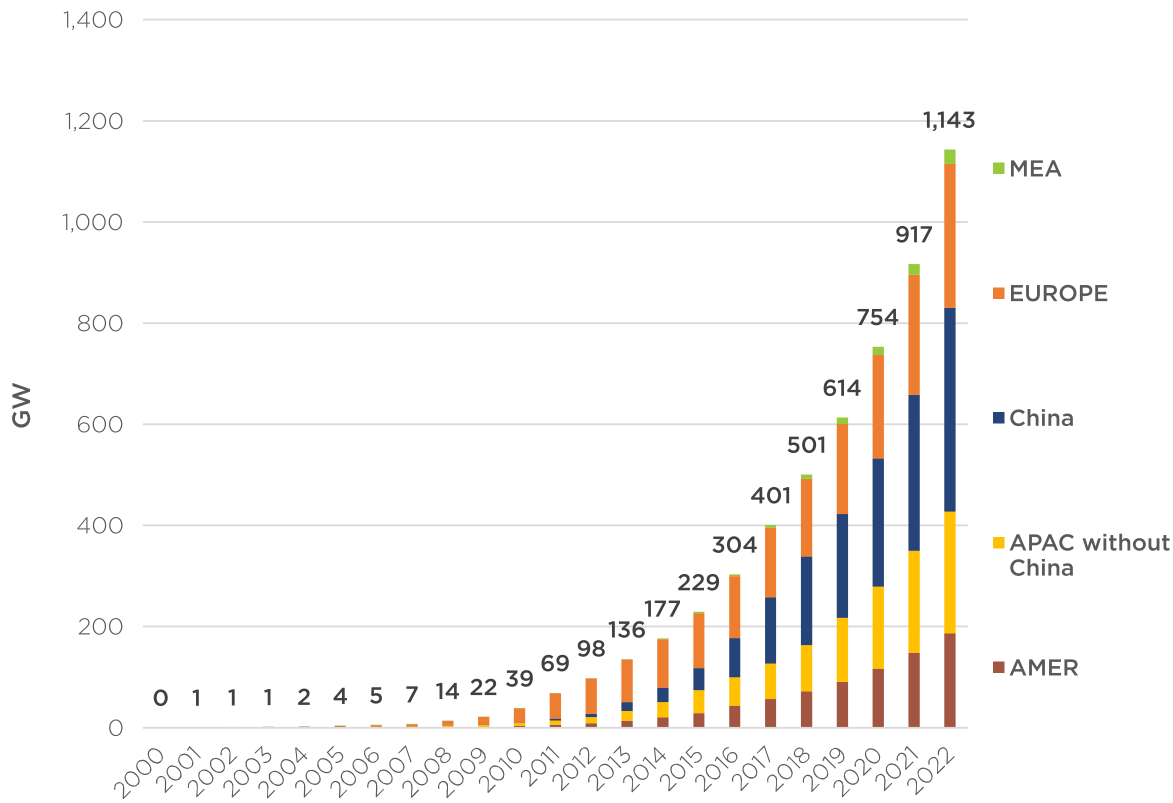


Figure 7: Cumulative global solar PV deployment 2000, 2022

Source - SPE, IRENA, IEA, BNEF, S&P Global

3.1.2. Regional distribution

During the initial stages of solar PV development, the advancement of on-grid markets received significant momentum from two pioneering countries: Japan and Germany. Japan led the way by promoting solar adoption through the establishment of a Renewables Portfolio Standard (RPS) law, while Germany instituted a feed-in tariff (FIT) program. By 2004, these two nations emerged as frontrunners in the solar PV realm, achieving the remarkable feat of operating at a capacity of 1 GW. The period spanning from 2004 to 2011 is widely recognized as the inaugural "golden age" of solar PV in Europe. Throughout this phase, Europe held a commanding position in the global market, attaining annual installation shares ranging from 66% to 85%, as depicted in Figure 8. Germany maintained its growth trajectory, and several other European countries, such as Italy, Spain, France, and Belgium, surged beyond the 1 GW milestone in annual installations, predominantly propelled by favorable feed-in tariffs. Italy's exceptional achievement in 2011 is particularly noteworthy, establishing it as the European leader with a groundbreaking connection of 9.2 GW, a record that still stands unchallenged on the continent, but is expected to be dethroned in 2023. This initial phase of European solar PV expansion concluded after 2011, marked by a reduction in solar PV support schemes, as European nations grappled with intricate political and financial challenges, including the debt crisis. Consequently, the European solar market contracted from 21.9 GW in 2011 to a more modest 7 GW in 2016, opening doors for the **Asia-Pacific (APAC)** region to assume a prominent role in the global solar landscape.

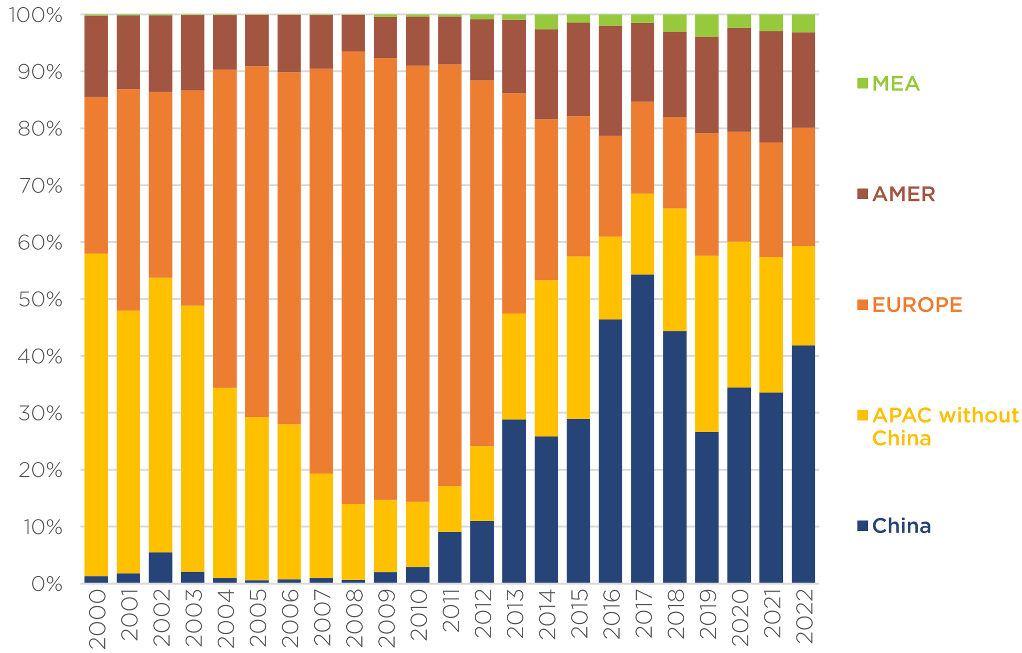


Figure 8: Regional share of annual solar PV deployment, 2000 - 2022
Source: SPE, IRENA, IEA, BNEF, S&P Global

This rise was fueled by three major economies within the region: China, India, and Japan. In a collective display of dominance, these countries orchestrated the installation of 89% of the 21.6 GW that the APAC region introduced in 2013, and 51% of the global tally of 37.9 GW. From 2013 onwards, APAC has consistently maintained its supremacy as the primary solar PV hub, consistently holding over half of the global market share.

In 2022, the Asia-Pacific (APAC) region has further solidified its position as a global solar leader, augmenting its share by 2 percentage points and securing a substantial 59% of the annual installed capacity in 2022. However, the story of solar in the APAC region is inherently linked to China whose installations rose sharply and reached a staggering 94.7 GW in 2022. When excluding China from the APAC perspective, the region's global market influence diminished from 24% to 17%. This starkly underscores China's significant impact, as its global market share surged from 34% to an impressive 42% within a single year. The rest of APAC only marginally progressed, from 39 GW in 2021 to 40 GW in 2022. A closer look at the performance of other pivotal regional players highlights an intriguing observation: India's modest growth of 3.2 GW proved insufficient to counterbalance the slowdown experienced in Australia and South Korea. These two nations together witnessed a substantial drop of nearly 4 GW in their annual market.

Europe remains the second-largest region for annual solar PV deployment. The solar industry's robust performance led to a significant surge in annual installed capacity. The region observed a remarkable year-on-year growth of 14.1 GW or an increase of 43 percentage points, having successfully installed a total capacity of 47.1 GW in 2022. This contribution accounts for a global market share of 21%. Spain has emerged as the new solar frontrunner in the region, contributing 8.4 GW and overtaking the leadership from Germany, which installed 7.4 GW. In addition to this, Poland (4.5 GW), the Netherlands (4.0 GW), and Italy (2.5 GW) all surpassed their performance from the previous year.

Since the 2000s, the **Americas** have displayed a more consistent path of development, marked by incremental growth. This expansion has been primarily driven by prominent players like the United States and Brazil, along with smaller contributions from Mexico and Chile. Over the past decade, the solar PV annual share of the American continent has undergone a notable ascent, surging from 8% in 2011 to a commendable 17% in 2022. This translates to a newly installed capacity of 38 GW, up from the 32 GW installed in 2021.

Despite the rising annual market, the continent's global market share has actually diminished, indicating a comparatively slower adoption of the technology compared to the APAC and Europe regions. The share held by the Americas declined from 19.6% in 2021 to 16.7% in 2022, marking the first decrease since 2017 when it accounted for 14% of the annual PV market. This decline can be attributed to the contraction of the largest regional market, the United States, which saw its yearly market size decrease from 23.4 GW to 21.9 GW in 2022. As a result, the dominant position of the US in 2022 has somewhat weakened, creating an opportunity for another significant contributor in the two-digit GW solar realm from South America: Brazil. The country experienced a remarkable surge in its annual installed capacity, jumping from 5.5 GW in 2021 to an impressive 10.9 GW in 2022.

While the driving forces for solar expansion in the region during 2022 remained consistent with the previous year, with the US and Brazil leading the way, Chile has also further solidified its increasingly pertinent role on the continent. It achieved this by elevating its solar capacity from 1.3 GW to 1.8 GW.

On a lesser scale, the market in the **Middle East and Africa (MEA)** has experienced gradual growth, albeit with a higher degree of volatility. This growth has largely been spurred by substantial multi-gigawatt projects initiated through government tenders on the Arabian Peninsula. In 2022, the MEA region accomplished an installation of 7.1 GW, a record-year for the region accounting for a 3% share of the global market. Israel has taken the lead as the Middle East's primary solar market, crossing the GW threshold for the first time by adding slightly over 1 GW of new capacity, up from 935 MW in 2021. Meanwhile, in Africa, South Africa has maintained its prominent stance by installing 1.3 GW of solar capacity in 2022, aligning with last year's projections of achieving GW-scale capacity. Within the region, the Middle East and Northen Africa (MENA) remains larger than the Subsaharan countries where on-grid PV expansion struggles to take off outside of South Africa.

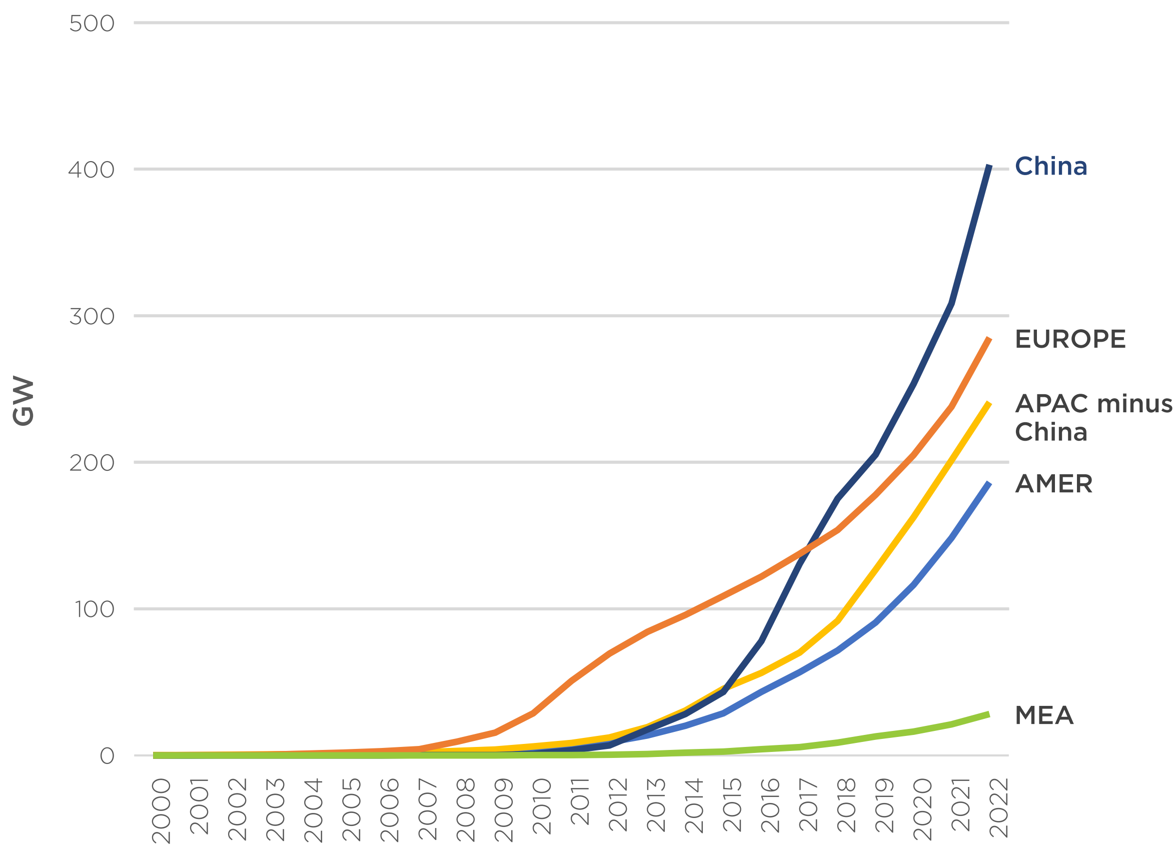


Figure 9: Cumulative global solar PV deployment, 2000-2022
Source: SPE, IRENA, IEA, BNEF, S&P Global

3.1.3. Segmentation

Table 1 State of solar PV segmentation at the end of 2022

	Residential	Commercial	Utility-scale
Annual (226 GW)	22%	28%	50%
Cumulative (1,143 GW)	18%	27%	55%

Table 2 Compound Annual Growth rate of annual addition per segments in the period 2020-2022

	CAGR (2020-2022)
Residential	40%
Commercial	26%
Utility-scale	23%
Global	27%

In the early days of solar PV, rooftop installations, particularly small-scale residential systems, led the way, later giving precedence to commercial and industrial (C&I) applications. Between 2000 and 2005, rooftop solar PV contributed over 90% of the global annual capacity. Utility-scale installations began gaining momentum later in 2006, gradually reducing the rooftop sector's share. By 2013, utility-scale solar PV installations exceeded rooftop installations for the first time, capturing a 62% share of annual capacity additions. This dominance persisted, with utility-scale installations consistently making up around 65% of annual installations.

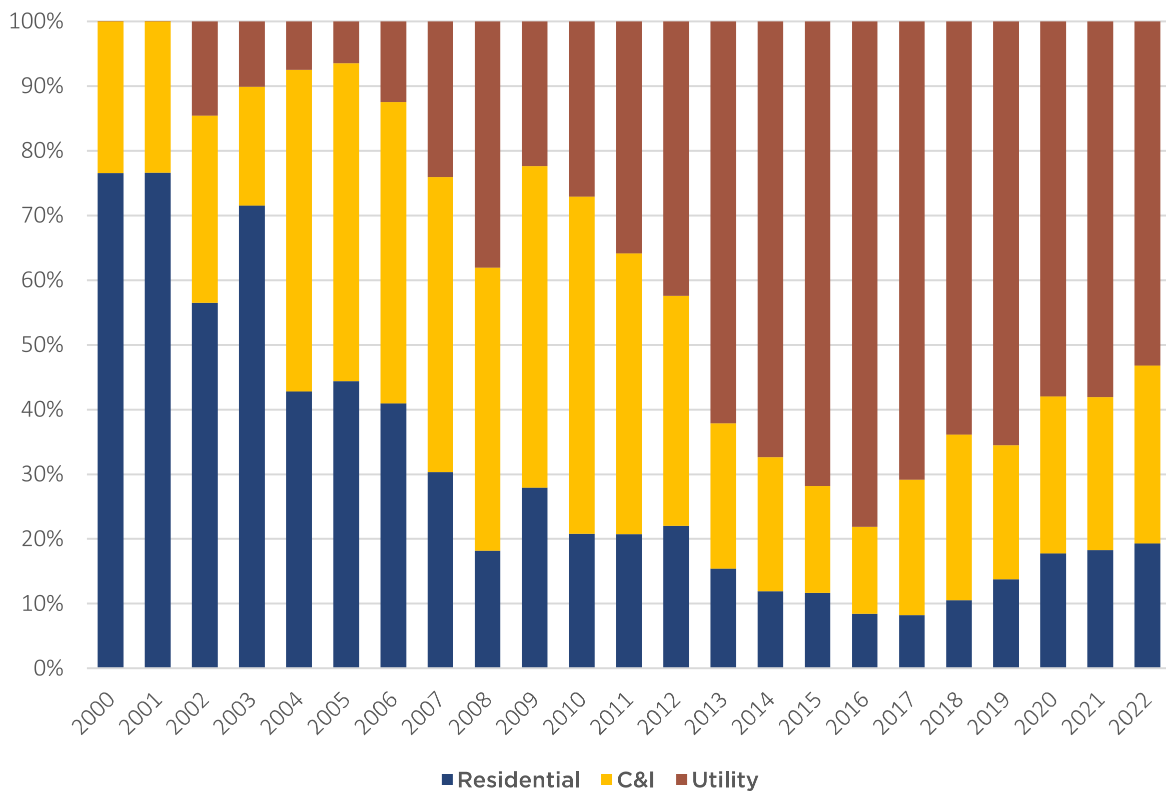


Figure 10: Annual global solar PV deployment per segment, 2000-2022
Source: SPE, BNEF, S&P Global

Modern solar PV markets take a different path. They tend to start with large-scale installations through tenders and auctions, leading to swift and cost-effective growth. This contrasts with nurturing a high-volume rooftop solar market, which requires time for legislative framework establishment and awareness building. However rooftop solar holds an advantage with its higher public acceptance, being integrated into buildings and avoiding land conflicts. Moreover, its proximity to consumption points reduces grid costs and promotes decentralized energy systems.

While solar PV segments show global growth, their relative shares have fluctuated. After peaking at over 70% in 2016, utility-scale installations reduced to 58% in 2021 and 53% in 2022. Two main factors explain this drop. First, utility-scale projects are more sensitive to price fluctuations and supply chain disruptions which followed the pandemic of

COVID-19. With higher components prices, several utility-scale projects got delayed, or canceled. Second, the rising power costs following the Ukrainian war have driven residential and C&I customers towards rooftop solar to shield from high electricity prices.

As a result, in 2022, the overall rooftop solar market witnessed a significant surge of 54%, with installations reaching 105 GW, as compared to the previous year's 69 GW (see fig 11). This noteworthy increase in solar adoption within residential and commercial sectors underscores a strong a strong desire to generate and consume cheap and clean electricity autonomously. Coinciding with this, utility-scale solar PV installations also expanded by 26%, achieving a newly added capacity of 120 GW, despite facing elevated module prices throughout 2021 and 2022.

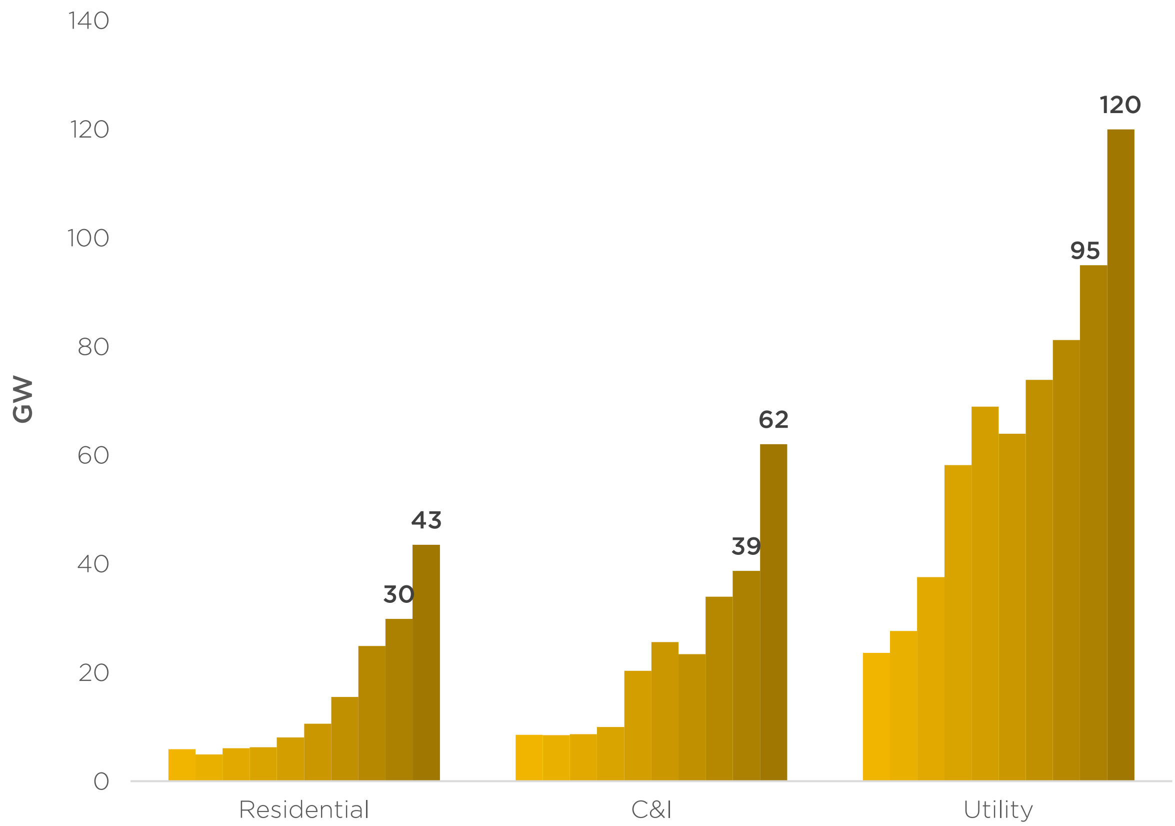


Figure 11: Annual global solar PV deployment per segment, 2013-2022
Source: SPE, BNEF, S&P Global

Although large-scale systems continued to contribute predominantly to the overall capacity, utility and rooftop solar shares have never been that close to parity in recent years. Utility-scale installations accounted for 53% of total additions, while rooftop contributed at 47%. The growth of utility-scale solar could have been even more substantial if not for the persisting disruptions in supply chains and the increased costs of PV components, largely attributed to the aftermath of the COVID-19 pandemic and the Ukrainian conflict.

Nevertheless, the growth of the rooftop segment exhibited variation across different countries. Notably, among the top 20 solar markets, Australia, South Korea, and Japan were the only countries to report a decline in rooftop installations compared to the prior year. Australia observed the sharpest decline, with a decrease of 2.3 GW in comparison to 2021, marking a decline of 46%. Similarly, South Korea's rooftop installations decreased by 1.1 GW in 2021 (-33%). In Japan, the rooftop sector contracted by a marginal 0.5 GW (-9%). Conversely, most other major markets reported robust expansions. Brazil stood out with impressive progress, adding a substantial 5.3 GW and reflecting a remarkable growth rate of 193% from 2021. This surge was largely driven by installations aiming to capitalize on the favourable conditions of the net-metering scheme before anticipated rule changes in 2023. Meanwhile, Mediterranean nations Italy and Spain also achieved notable advancements, with their rooftop markets expanding by 127% and 105%, respectively.

3.1.4. Top 15 countries

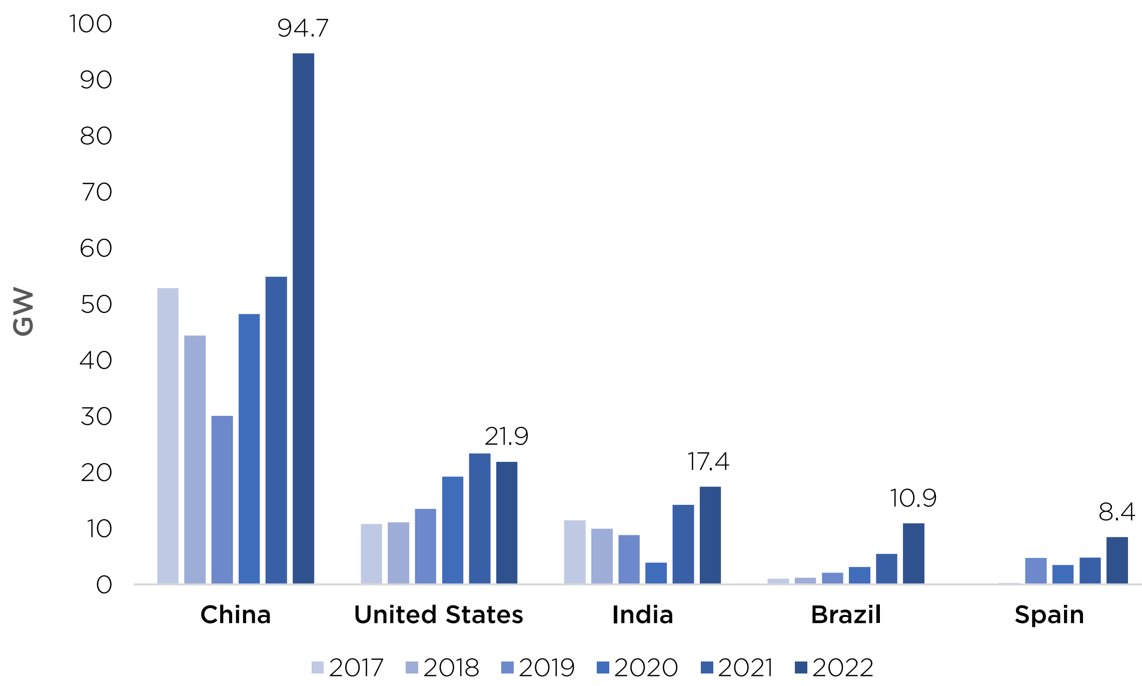


Figure 12: Top 5 annual solar PV addition 2017-2022 (2022 ranking)
Source: SPE

Most of the leading solar markets in 2022 maintained their standings from the prior years, yet there were notable changes in rankings and the inclusion of new entrants owing to diverse growth patterns as shown in Figure 12.

In 2022, the Chinese market exhibited remarkable growth and accelerated it's rebound from the slowdown experienced in 2019 when it reached 30 GW. Subsequently, it achieved installations of 48.2 GW in 2020, 54.9 GW in 2021, and an astonishing 94.7 GW in 2022 (a 72% annual growth). While the 2021 installations marginally surpassed the previous record of 52.8 GW set in 2017, 2022 signifies a distinctive new phase of growth and further solidified China's position as the frontrunner in the solar market. This is exemplified by its installation being over four times larger than the second-largest solar PV market, the United States. Remarkably, China's capacity additions for 2022 even exceeded the combined capacity added by the following top nine markets. The increasing competitiveness of solar in both utility-scale and distributed applications, coupled with growing awareness of the attractiveness of solar power, are propelling demand within the world's second-largest economy. Notably, China's rooftop solar segment, driven by both residential and C&I installations, captured a significant share, accounting for 54% of the market in 2022. This dominance carried forward from 2021 when it contributed 53% to newly installed capacity. In 2022, China achieved a significant milestone by surpassing the 400 GW mark in total solar installations. This achievement came shortly after crossing the 300 GW threshold by a narrow margin just a year earlier.

In 2022, the solar market in the United States encountered a tumultuous period, yet managed to retain its position as the second-largest market. The nation achieved installations of 21.9 GW, reflecting a 6% decline compared to the previous year. This decrease occurred in a year marked by notable events such as anticircumvention investigations, the enactment of the Uyghur Forced Labor Protection Act (UFLPA), and the passage of the significant Inflation Reduction Act (IRA). This lackluster performance marked a break in the uninterrupted growth experienced since 2017. Similar to preceding years, the majority of installations originated from the utility-scale sector, constituting 13.8 GW or 63% of the total. However, this marked an 18% reduction from the 16.8 GW installed in 2021. The decline in the large-scale segment was primarily influenced by the detainments of products stemming from the US Customs' Withhold Release Order (WRO) and the UFLPA. Conversely, the rooftop segment experienced a notable upswing, witnessing a 25% growth to achieve 8.1 GW, mostly propelled by a robust residential demand.

In 2022, India's recovery continued, leaving behind the disappointing development period from 2018 to 2020. After enduring a persistent decline in solar demand from 2017 to 2020, dropping from 11.5 GW to a mere 3.9 GW, the country made a substantial turnaround. Following a record-setting year in 2021, India achieved a remarkable addition of 17.4 GW of solar capacity in 2022, surpassing the 2021 record by more than 3 GW. This accomplishment solidified its third-place position. India's journey exhibited a robust 23% annual growth rate, a trajectory expected to persist as the nation targets 500 GW of non-fossil fuel electricity capacity by 2030 and commits to attaining net-zero carbon emissions by 2070. However, despite these impressive strides, India confronts challenges within its solar industry. The country faced significant setbacks due to the impact of COVID-19, leading to delayed projects attributed to supply chain disruptions. Additionally, the introduction of the Basic Custom Duty in 2022, which imposed a 40% duty on imported modules and 25% on cells, has posed financing difficulties for numerous projects. Furthermore, the rooftop solar market remains underdeveloped, adding only 4.9 GW in 2022, representing 28% of annual installations. The cumulative rooftop solar capacity reached around 10 GW by the end of 2022, significantly falling short of the 40 GW that was targeted for rooftop solar at the end of 2022. This shortfall is considered the primary reason why India missed its 100 GW solar target by a substantial margin, achieving a total of only 77 GW. Surmounting these challenges will be pivotal for India to further accelerate its adoption of solar energy and realize its ambitious renewable energy objectives.

Emerging onto the scene in 2021 as the 7th top solar market, Brazil has now elevated its standing to the 4th position in the latest rankings, becoming the solitary Latin American representative within the top 10 cohort. Remarkably, the country achieved the installation of 10.9 GW of solar capacity in 2022, essentially doubling its prior record of 5.5 GW set in 2021. Of last year's installations, a substantial portion of approximately 8 GW originated from distributed solar systems with capacities of up to 5 MW. This segment thrived under an attractive net-metering scheme until the end of 2022. However, the rules for this scheme have undergone revisions for projects developed from 2023 onwards, introducing new grid-connection fees. Consequently, a surge of installations transpired in 2022, driven by consumers keen on avoiding the new grid fee, and accessing the more advantageous scheme. The Brazilian solar sector also witnessed growth in centralized systems, totaling 1.5 GW. This growth primarily stemmed from energy auctions targeting large-scale power plants, along with the establishment of some power purchase agreement (PPA) based systems. Brazil's remarkable ascent in the solar market highlights the nation's inherent potential and burgeoning interest in renewable energy. Despite the challenges presented by its grid which need investments and reinforcement , Brazil's solar sector showcased a robust expansion in both distributed and centralized solar installations. However, a contraction in the market is projected in the short term due to less favorable net-metering regulations.

Spain's ascent in the solar rankings has been a gradual journey, advancing from the 9th spot in 2020 to the 8th position in 2021, and 2022 made a significant leap by three positions, now securing a place within the top 5 solar markets. The nation achieved a substantial newly installed capacity of 8.4 GW in 2022, marking an impressive 76% surge from the previous year's 4.8 GW. A striking feature of Spain's solar landscape is its substantial development pipeline, exceeding 100 GW of unsubsidized solar projects. However, due to permitting challenges and grid limitations, only small portions of this pipeline materialize each year. Nevertheless, it remains a key driver behind its progress and boosts Spain's robust PPA-driven utility-scale segment which contributed to 5.3 GW of installations in

2022 without relying on subsidies. This trend is poised to continue, as Spain streamlined environmental permits for over 25 GW of solar PV projects in early 2023. Additionally, the self-consumption rooftop market played a pivotal role in Spain's 2022 advancements with the addition of 3 GW of new capacity, doubling its market size within a year. This growth has been facilitated by policy enhancements and rising electricity prices triggered by the energy crisis.

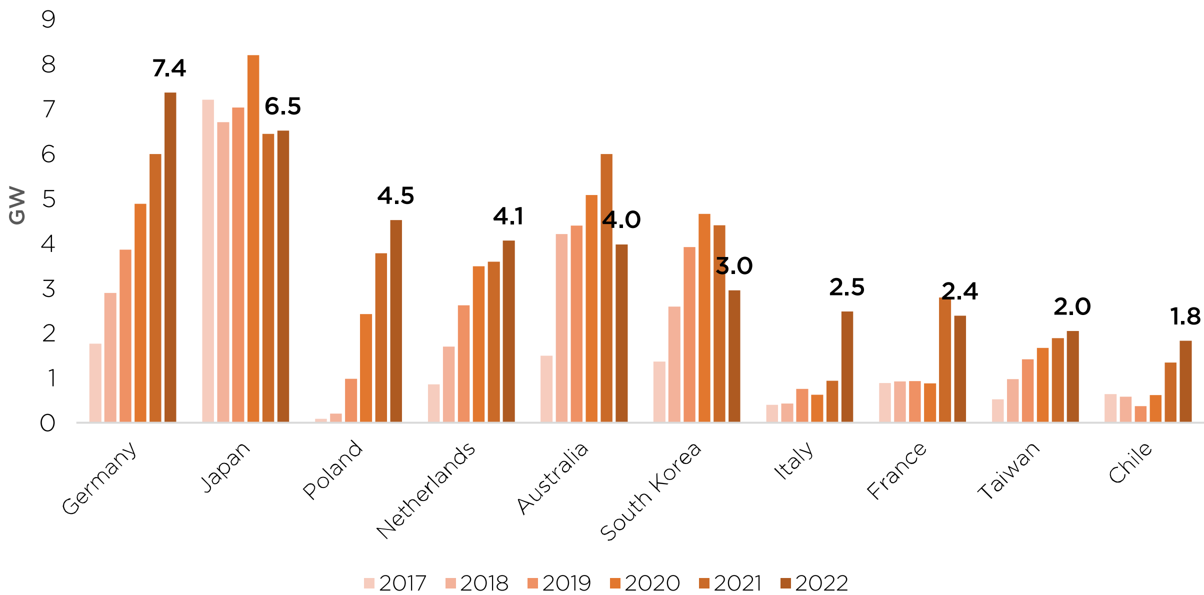


Figure 13: Top #6 to #15 annual PV addition 2017-2022 (2022 ranking)

Source: SPE

Ranking as the second-largest European market in this assessment, Germany maintained its #6 position, mirroring its spot from 2021. Notably, the country experienced a substantial 23% expansion in grid-connected solar capacity, achieving 7.4 GW in 2022, compared to the previous year's 6 GW. Germany mainly relies on rooftop installations, supported by a reliable feed-in premium program and regular tenders for systems over 750 kW. The country's high electricity price is also boosting the rooftop trend as households increasingly opt for self-consumption coupled with battery storage. Conversely, the augmentation of tender volumes in 2019 is playing a pivotal role in the increase of the utility-scale segment which escalated from 2.2 GW in 2021 to 3 GW in 2022. The German government also acknowledges the significance of solar power and has set ambitious goals. These goals encompass renewables making up 80% of total power generation by 2030, achieving full reliance on renewables by 2035, and striving for an impressive 215 GW of solar PV capacity by 2030.

Japan's solar market trajectory took a flatter course, resulting in a decline in its ranking from 4th place in 2021 to 7th in 2022. The country added 6.5 GW of solar capacity in 2022, which mirrored the performance of 6.4 GW in 2021 but represented a 21% decrease from the 8.2 GW achieved in 2020. The bulk of the new capacity in 2022 can be attributed to projects approved under feed-in tariff (FIT) and feed-in premium (FIP) mechanisms established a few years ago. With the FIT era concluding at the end of 2022, the market has entered a transitional phase, leading to stagnation in installation levels. Meanwhile, new business models centered around power purchase agreements (PPAs) and third-party ownership are gaining traction.

Poland is on an exponantial curve and advanced two positions to secure the 8th rank. The country added 4.5 GW of solar capacity in 2022, marking a 20% expansion compared to the previous year. Solar development has been predominantly spurred by small rooftop systems under 50 kW which represented almost 80% of the newly installed capacity. This category benefitted from a favorable net-metering scheme until March 2022, subsequently replaced by a net-billing system. Following this legislative change, the outlook for the small rooftop market remains uncertain and the market is now slowly shifting focus towards the large-scale segment. Numerous companies are considering solar PV to secure their energy supply through PPAs, especially following the increase in energy price. The solar market is facing few regulatory hurdles, but the aging transimission infrastructure and changes to the Spatial Planning and Development Act could potentially pose challenges for the long-term growth of large-scale PV projects in Poland.

A prominent actor in the European stage for several years, the Netherlands marked its debut on the global stage, securing the 9th position in 2022. With an installation of 4.1 GW, the country continued its upward trajectory, surpassing the 3.6 GW added in 2021 (a 13% YoY increase) and the 3.5 GW in 2020 (a 2% YoY increase). Growth in the residential segment keeps playing a pivotal role, contributing with a success attributed to the appealing net-metering policy. Conversely, the C&I segment encountered challenges arising from rising costs, resulting in a minor loss of momentum. Nonetheless, the Dutch solar market maintains a well-rounded balance among its various sectors, positioning the nation as a European leader in solar capacity per capita. Recognizing the limited space available for ground-mounted installations, the industry is exploring innovative solutions like on- and off-shore floating solar and solar carports. Additionally, efforts to involve local communities in renewable energy initiatives aim to enhance social acceptance and integration.

Australia, now seated in the 10th spot of the global ranking, has descended by five places. In 2022, the Australian solar market encountered a setback, breaking its streak of uninterrupted progress since 2014. The year saw 4 GW deployed, marking a 34% decline from the record-breaking 6 GW added in 2021. Despite this, Australia maintains its position as the leader in solar power per capita worldwide. The business landscape faced challenges stemming from the Russian invasion in Ukraine and rising component prices, constraining overall sector growth. However, the election of a government that supports renewables and climate action is expected to foster a favorable environment for renewable energy deployment. Moreover, recent improvements in PV component prices have already led to a surge in solar installations compared to the early months of 2023.

Beyond the top 10, South Korea dropped two spots and fell at the 11th position with 3 GW installed in 2022. The Korean market has been adversely affected by the country's change in political direction towards nuclear energy and a decrease in its renewable target from 30.2% to 21.6% by 2030. This shift has led to a decline, with the downward trend projected to continue. Italy, landing at the 12th spot with 2.5 GW, managed to increase its annual installations from less than a GW in 2021. Most of the installations are residential rooftops steeming from the advantageous Superbonus 100% scheme. In France, the annual market fell a bit short of its 2021 level, with a 15% reduction to land at 2.4 GW, and at the 13th global position. Nevertheless, it remains substantially higher than the previous period from 2013-2020 when the market stangnated at level between 600-900 MW per year. Taiwan and Chile secured the 14th and 15th positions in the global solar PV market in 2022, with 2 GW and 1.8 GW, respectively. Taiwan's growth has been consistent but is slowing down, while Chile is accelerating its deployment and experienced its best year ever, despite internal political challenges linked to its energy sector.

Table 3 Top 10 Annual markets 2018-2022

	2018	2019	2020	2021	2022
1	China	China	China	China	China
2	United States	United States	United States	United States	United States
3	India	India	Vietnam	India	India
4	Japan	Japan	Japan	Japan	Brazil
5	Australia	Spain	Australia	Australia	Spain
6	Germany	Vietnam	Germany	Germany	Germany
7	South Korea	Australia	South Korea	Brazil	Japan
8	Mexico	Ukraine	India	Spain	Poland
9	Netherlands	South Korea	Spain	South Korea	Netherlands
10	Turkey	Germany	Netherlands	Poland	Australia
Annual deployment required to enter the top 10	1.6 GW	3.9 GW	3.5 GW	3.8 GW	4.0 GW
Number of GW markets	11	16	17	17	26

An analysis of the top 10 solar markets from 2018 to 2022 (Table 3) reveals that while the leading positions remain relatively stable, the lower ranks exhibit greater dynamism. China consistently maintains its dominance in the top position, while the US has held the second-largest market status since 2018. India consistently lands in the top three, except for 2020 when regional financial conditions created turbulence. The mature Japanese market maintained a steady installation level, until 2022 which marks it's lowest rank ever. Established markets like Germany and Australia consistently appear in the top 10, while shifts in regulatory and investment conditions determine the inclusion or removal of other countries from the list.

The criteria for entering the top 10 club increased from 1.8 GW in 2018 to 3.9 GW in 2019 but remained rather constant until 2022 with 4.0 GW. More importantly, 26 countries have reached at least 1 GW of yearly annual installation in 2022. This is sharp increase compared to the previous years, and exhibit the increasing popularity of solar PV into various national energy strategies. This also explains why some previously well established markets that plateaued in 2022 – such as Japan and Australia – are losing ranks in the ranking.

3.1.5. Watt per capita

Shifting the focus of analysis to different metrics reveals distinct disparities both between and within regions. Looking at the Watt per capita (W/c) offers a direct comparison across countries of varying sizes, presenting an alternative perspective of the global solar landscape.

Table 4 Ranking of countries in Watt per capita, cumulative PV in 2022, annual PV in 2022

	Country	Watt/Capita	Ranking per cumulative installation 2022	Ranking per annual installation 2022
1	Australia	1.191	6	11
2	Netherlands	1.029	13	10
3	Germany	815	5	7
4	Denmark	713	31	18
5	Japan	677	3	8
6	Belgium	667	22	31
7	Estonia	601	57	56
8	Spain	572	7	6
9	Switzerland	535	28	28
10	Greece	531	26	20
...				
17	United States	417	2	2
26	China	283	1	1
64	India	55	4	3
	World	**144**		

While the podium in W/c has not changed with Australia, the Netherlands and Germany taking the lead, the two leaders have now surpassed the 1 kW of installed capacity per inhabitant, a landmark that was achieved by Australia alone in 2021. Interestingly, those are markets strongly supported by their rooftops segment, demonstrating the strength of distributed solar capacity. The rest of the ranking has seen numerous changes. Denmark has seen an impressive jump with 288 W/c added from 2021, allowing the country to rank up from the #7 position to #4 despite the uncertainties that lingered on its market following the introduction of higher grid fees. Denmark progression has pushed down both Japan and Belgium by one spot. Estonia made a strong entry in the top 10 to secure the 7th spot thanks to a steadily growing PV market in the last three years, which was accelerated by the Ukrainian war. The Nordic state is followed by a larger, and much southern country: Spain at 572 W/c. Switzerland climbed one spot and landed at the 9th position, while Greece is a newcomer to the club and close this top 10 with 531 W/c. Compared to last year, Malta, Luxembourg, and South Korea have all lost their ticket to the largest countries in installed capacity per inhabitant. Another impressive sign of growth is that all top 10 markets have passed the 500 W/c mark in 2021,something that was only achieved by the top 5 markets in 2021.

Once more, the leading markets of 2022 in terms of installed capacity – China, the United States, and India – are absent from the W/c top 10 (see Table 4) and each experienced a decline in their rankings in 2022. The United States dropped by 2 positions, moving from #15 to #17, while China slipped by 1 spot, and India's ranking plummeted by 6 positions. The global Watt per capita increased from 119 to 144.

Significant regional disparities are evident as well. While the APAC region added almost three times the PV capacity of Europe in 2022, the latter takes a substantial lead on a per capita basis, with 54 W/c added compared to APAC's 36 W/c (see Fig. 14). Notably, Europe has held the leading position among continents since 2019, and 2022 marks the largest increase ever, showing the fastest growth across all regions. The AMER region comes second with 36 W/c added in 2022, while MEA is lagging behind with only 4 W/c added in 2022. Impressively, Europe, AMER, and APAC all added around 15 W/c only five years ago in 2018. Since then, they progressed by a factor of 4, 2.3, and 2 respectively.

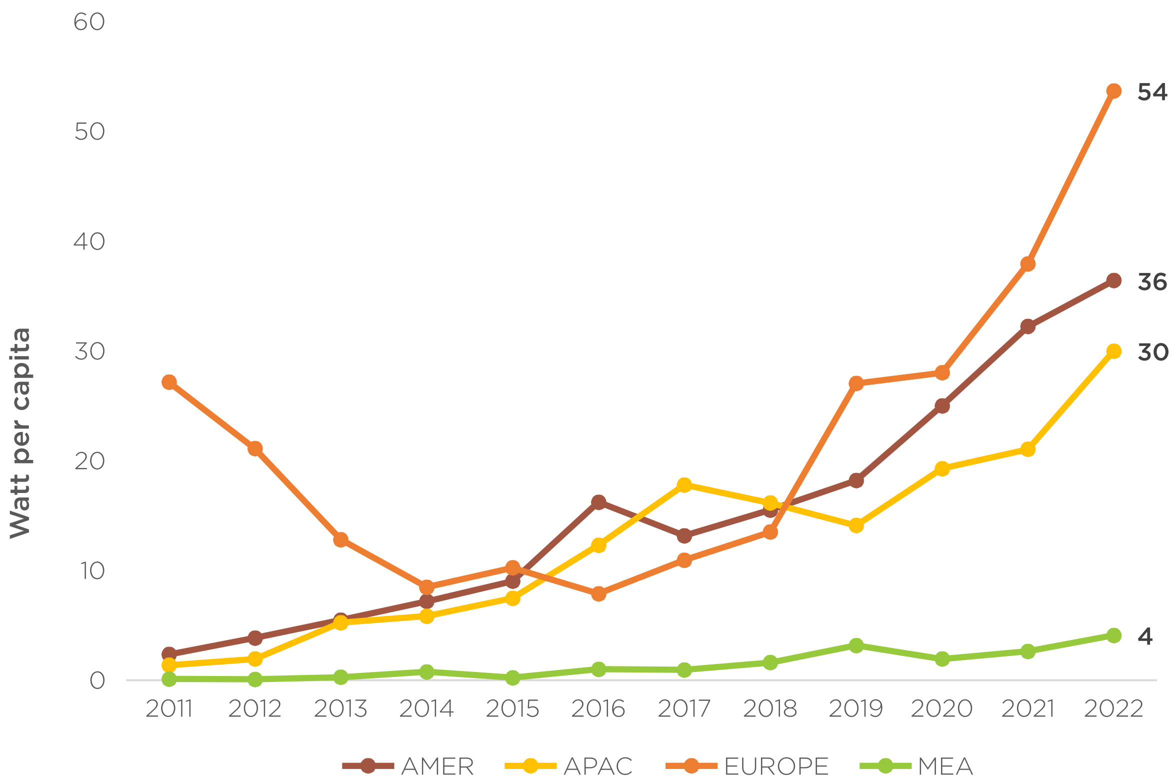


Figure 14: Net increase in regional watt per capita by region, 2010-2022
Source: SPE

Those disparities are also reflected from a cumulative viewpoint, with different dynamics across continent (see Fig 15). Europe stands at 296 W/c, more than double the world average of 144 W/c. With 23 countries above the world average, most Europeans countries have already embarked on a solar journey, with several solar champions as the continent is home for 8 of the top 10 market in terms of W/c. Denmark has experienced the largest growth of the continent in 2022, with 288 W/c while the Netherlands continued its ascension and added 228 W/c, confirming its position as the European country with the highest solar PV capacity installed per inhabitant. The country's favorable net-metering policy for residential systems, and the SDE++ tender scheme for larger C&I and utility-scale PV are keeping the Dutch market close its maximum potential. Other impressive developments includes Estonia (+197 W/c), Spain (+172 W/c), Austria (+147 W/c), Greece (+134 W/c), and Poland (+119 W/c).

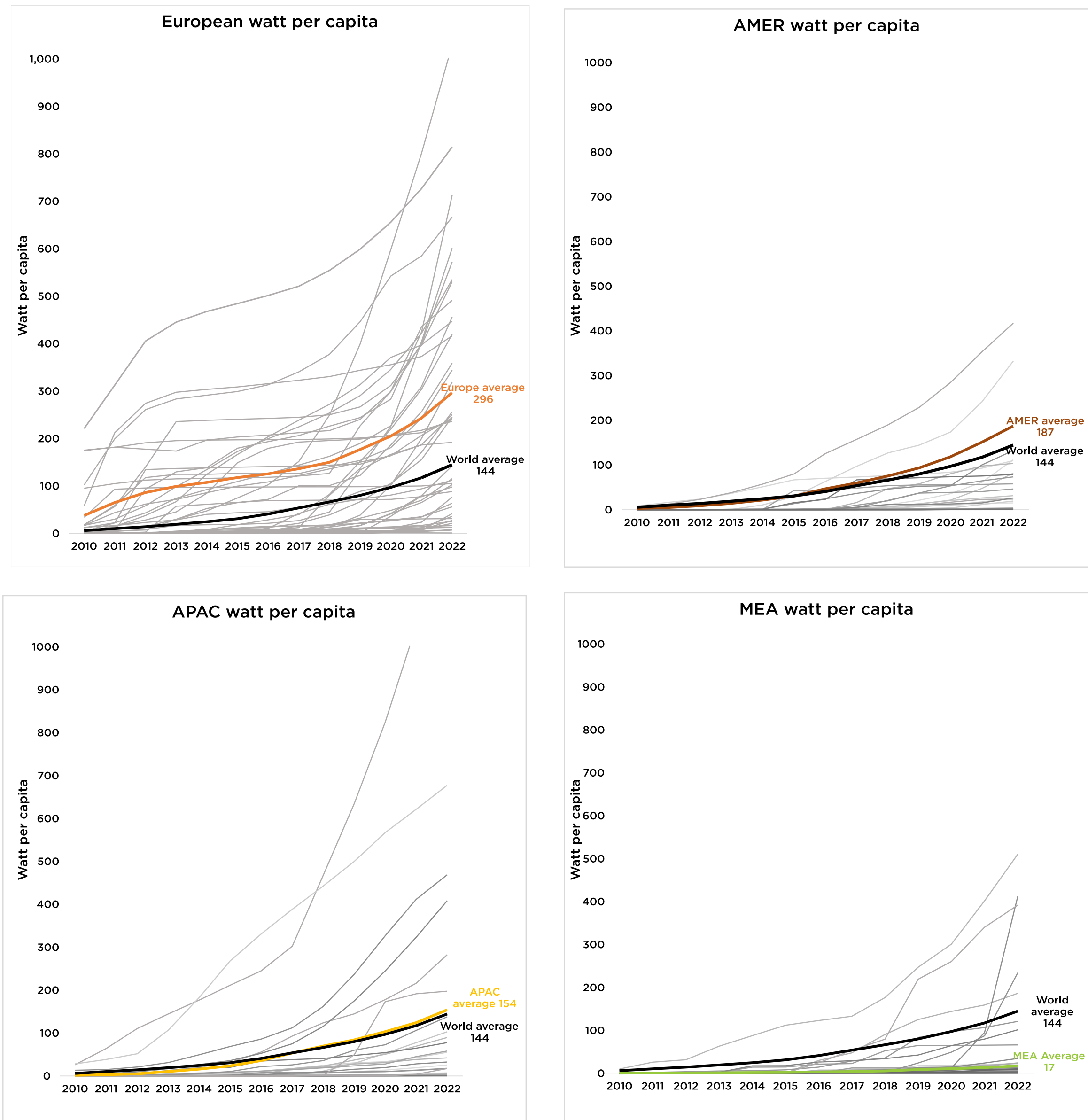


Figure 15: Regional watt per capita, 2010-2022

Source: SPE

The Americas stand at 187 W/c, with only two countries above the regional and world average: the United States and Chile. The United states, being the most populated country and having the largest solar fleet is heavily carrying the W/c average upward in the region. All other countries in the Americas are falling below the world average. The largest growth in the continent is coming from Chile, with an additional 91 W/c in 2022. Brazil almost doubled its total W/c from 61 W/c to 112 W/c in 2022. Nevertheless, to maintain growth in terms of capacity per capita, the remaining countries in the Americas must accelerate their adoption of solar energy, particularly in Latin America and the Caribbean. Despite constituting 66% of the continent's population, this region accounts for only 19% of the total PV capacity. Larger nations in South America, Colombia (20), Argentina (24), Peru (26), and Venezuela (0), are trailing behind in terms of Watt per capita.

The third region is APAC which progressed from 117 W/c in 2021 to 154 W/c in 2022, allowing the region to surpass the world average by a small margin. The APAC region notably stands out for hosting two of the most populated countries, India and China. Australia remains the leading country in the region with 1,191 W/c, with a comfortable margin over the second country, Japan with 677 W/c. South Korea, Taiwan, and China are following with 467, 408, and 283 W/c respectively. The only remaining country above the regional average is Vietnam, which experienced only minimal progression in 2022, most of its capacity having been connected during the feed-in tariff rush of 2019-2020.

Finally, the MEA region is trailing significantly behind with a mere 17 W/c, only one point higher than in 2021. Contributing to the regional average are notable nations like Israel, which recently exceeded 500 W/c, after having surpassed the 400 mark in 2021. and the United Arab Emirates at 318 W/c. With a population under 9.9 million and several large-scale multi-GW projects in development, the UAE holds the potential to contend for a spot in the top 10 in the upcoming years. However, the largest growth has been achieved by Qatar who jumped from 92 W/c in 2021 to 412 W/c following the completion of the Al Kharsaah solar power plan a capacity of 800 MW. This has propelled the peninsula at the first position of annual net increase in solar watt per capita (see Fig 16), and the 19th position in total installed capacity per inhabitant. Indeed, with a population of 2.7 millions people, the large plant has quadrupled the installed capacity in the country which now surpass 1 GW. Oman has followed the same path with the opening of the 500 MW Ibri 2 PV plant that propelled

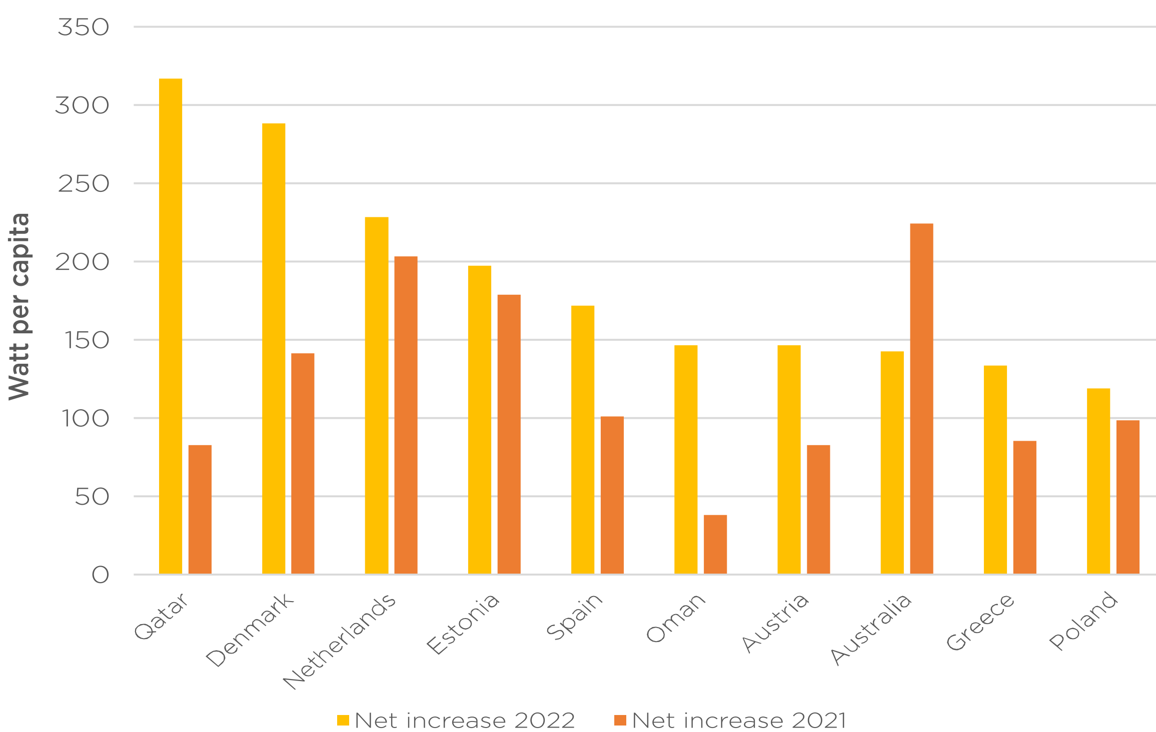


Figure 16: Top 10 net increase in watt per capita from 2021 to 2022
Source: SPE

the country to the 6th position with a 147 net increase of watt per capita. Important to note than the record 224 W/c added by Australia in 2021 has been largely surpassed in 2022 by three countries; Qatar, Denmark and the Netherlands.

Examining the worldwide distribution, as shown in Figure 17, reveals that almost 100 countries presently still possess solar capacities ranging from 0 to 50 W/c. This underscores the extensive untapped opportunity for solar PV adoption worldwide. Nonetheless, a gradual shift is observable as more nations are expanding their solar capacities. Consequently, a second bump in the distribution begins to emerge around the 400 W/c installed capacity mark.

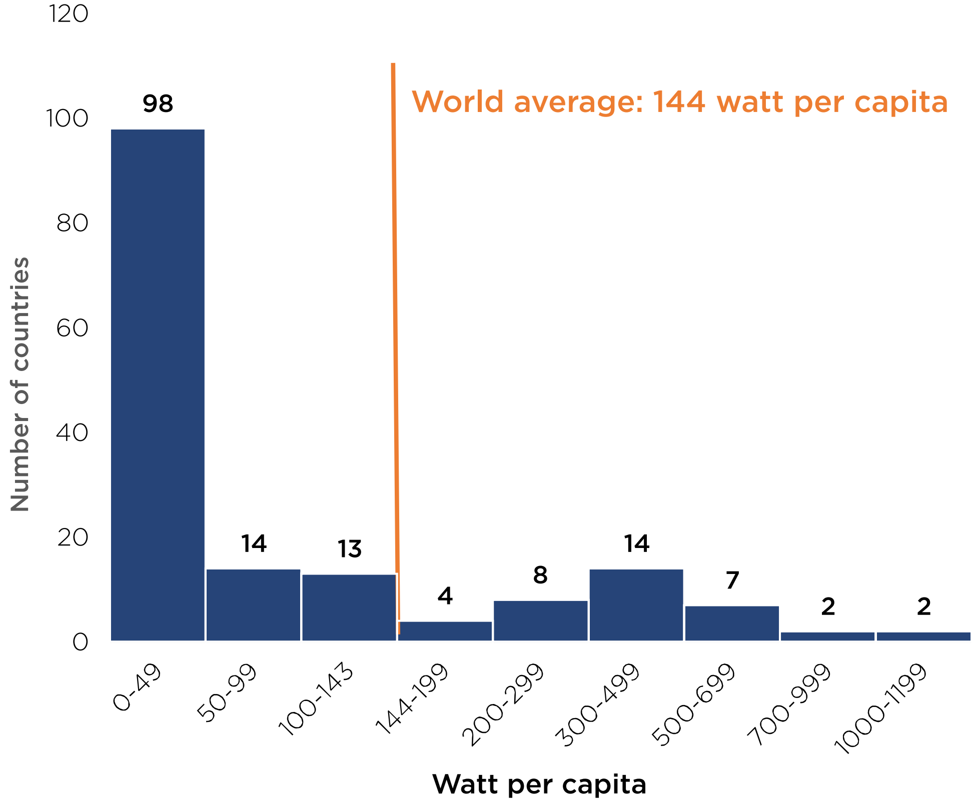


Figure 17: Distribution of countries in watt per capita

Source: SPE

3.1.6. Grid penetration

Despite the substantial growth the renewable sector has undergone in the past two decades, the global power generation sector is still dominated by fossil fuels, contributing 61.2% of the global electricity output in 2022 (Figure 18). This marks a 0.8 percentage point decrease from 2021 and a 0.6 percentage point decrease from 2020. In contrast, the decline in the share of renewable electricity generation observed in 2021 did not repeat itself in 2022; instead, the share increased from 28.2% to 29.6%. Then the generation coming from nuclear declined from 9.8% in 2021 to 9.2% in 2022.

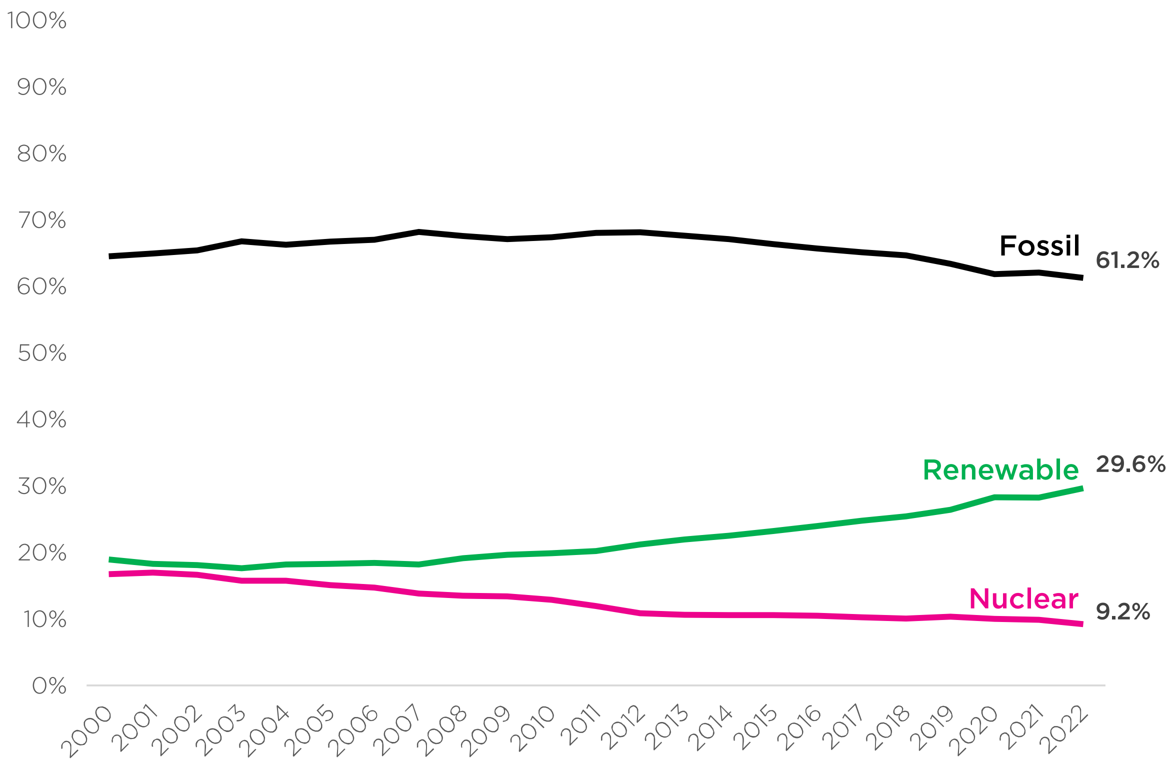


Figure 18: Share of global electricity generaton by source, 2000-2022
Source: Ember

The figure 19 highlights that one the primary factors contributing to the reduction in renewable generation in 2021 was a decrease in hydroelectricity output, particularly in Latin America and Asia due to drought conditions. Simultaneously, in 2021, coal utilisation experienced a resurgence to meet the growing power demand driven by the post-COVID-19 recovery phase which was tempered in 2022, when coal usage slowly decreased from 36.0% to 35.6%. In 2022, while the generation from hydroelectric sources kept decreasing, it did at a slower rate – from 15.2% to 15%, which marked a smaller decrease compared to the drop from 16.4% to 15.2% in 2021.

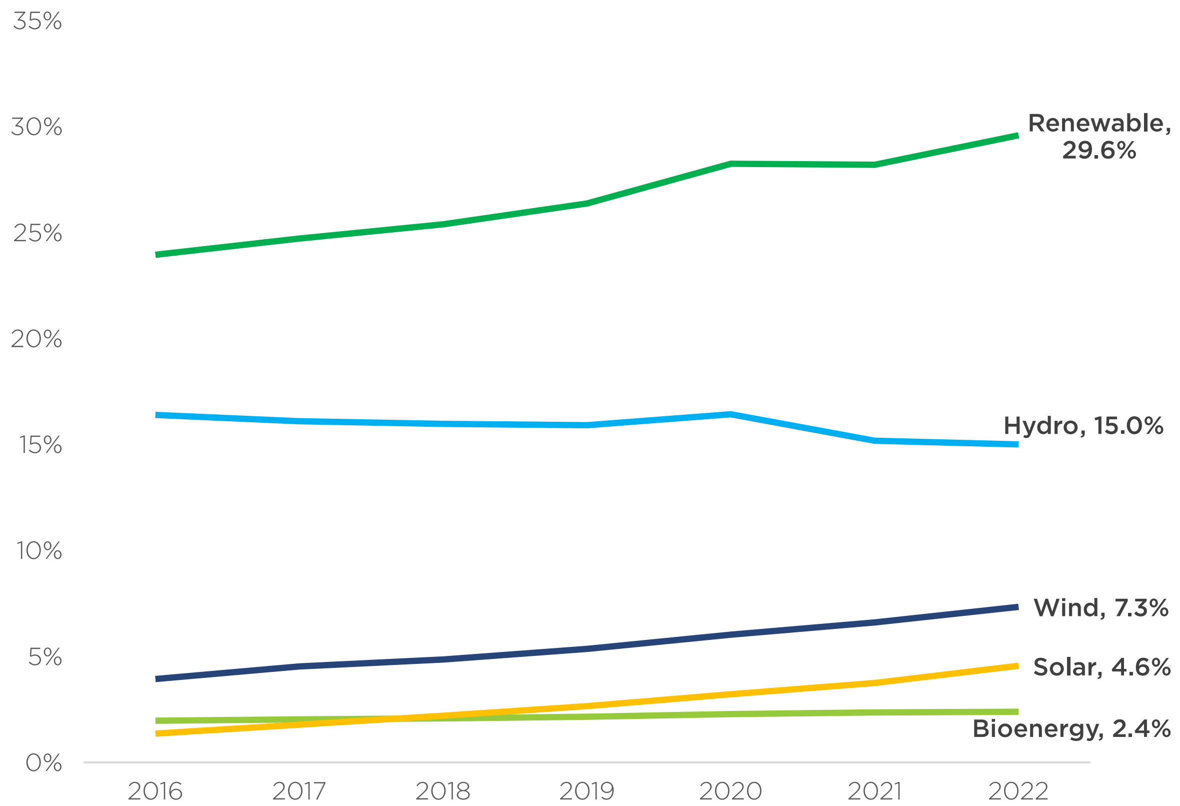


Figure 19: Share of global renewable generation by source, 2000-2022

Source: Ember

In 2022, the global electricity demand witnessed an increase of 675 TWh, reaching a total of 28,681 TWh. Examining the sources that were used to meet this additional demand paints a more positive picture compared to the previous year, where coal accounted for 48% of the new demand. In 2022, solar emerged as the primary technology used to address the new demand, covering 38.3% and representing an additional 259 TWh (see Fig 20). Wind closely followed with 37.5%, accounting for 253 TWh. Nonetheless, coal remained an important contributor to meet the new demand, with 118 new TWh and addressing 18% of the new demand.

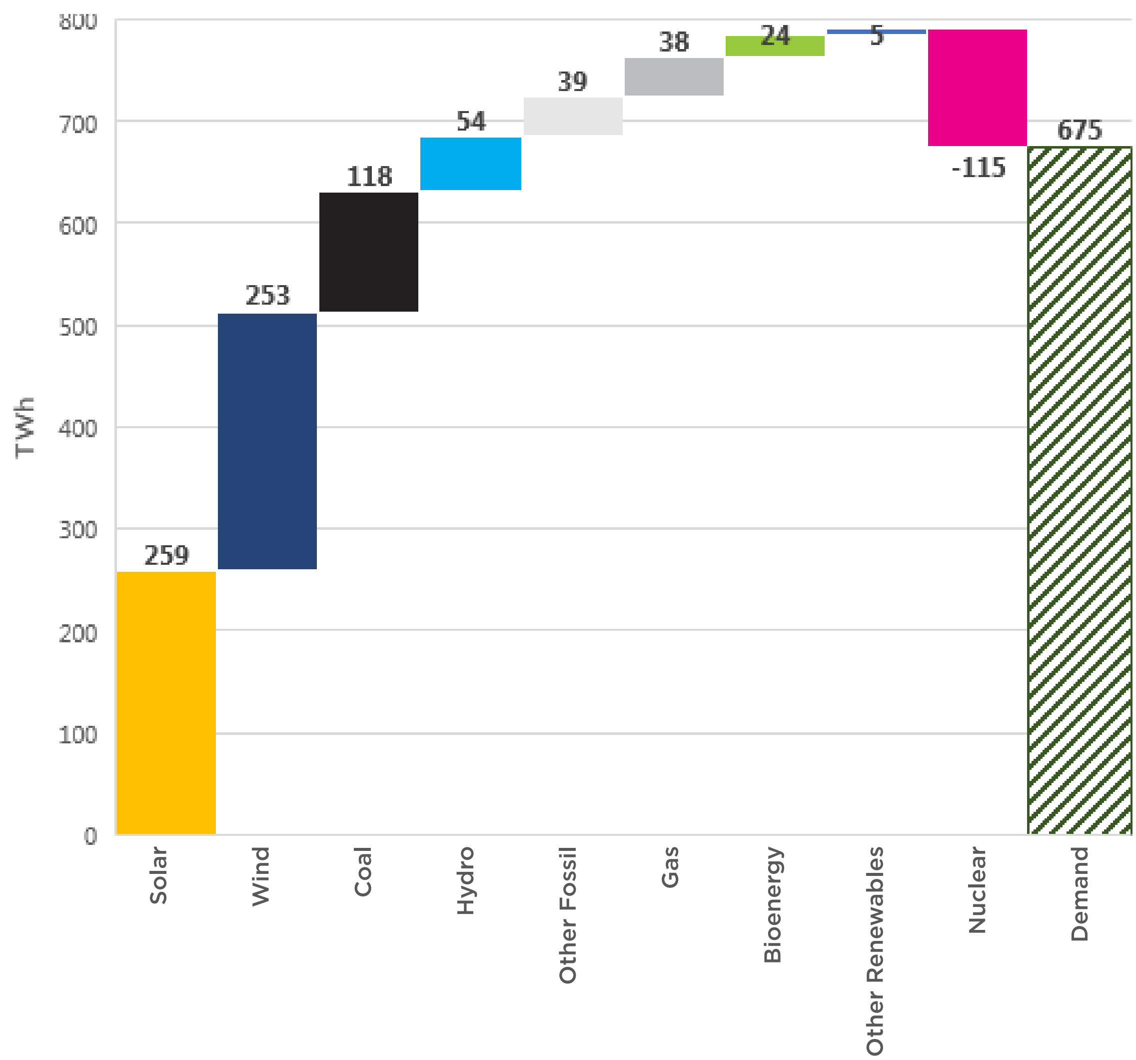


Figure 20: Power technologies used to meet global additional electricity demand in 2022
Source: Ember

Figure 21 examines the top 5 countries with higher shares of solar PV in the national electricity mix[3]. This figure holds particular significance because, within a scenario of global rising electricity demand, incorporating more PV doesn't automatically lead to reduced reliance on fossil fuels. Fossil fuels and renewable could rise simultaneously to answer increasing needs of electricity demand. Here, energy storage solutions will have to play a key role in the future as the their cost is coming down – and once administrations provide the right policy frameworks -, so they can support flexible renewable sources of electricity in meaningful way globally to fully replace fossil fuel energy. This scenario then doesn't translate into a relative decrease in the usage of fossil fuels. On the contrary, an increasing share of PV (or other renewable) in the electricity mix unmistakably signifies that renewable are growing faster than fossil fuels, which implies that renewables are displacing fossil fuels and indicates a genuine transition in progress.

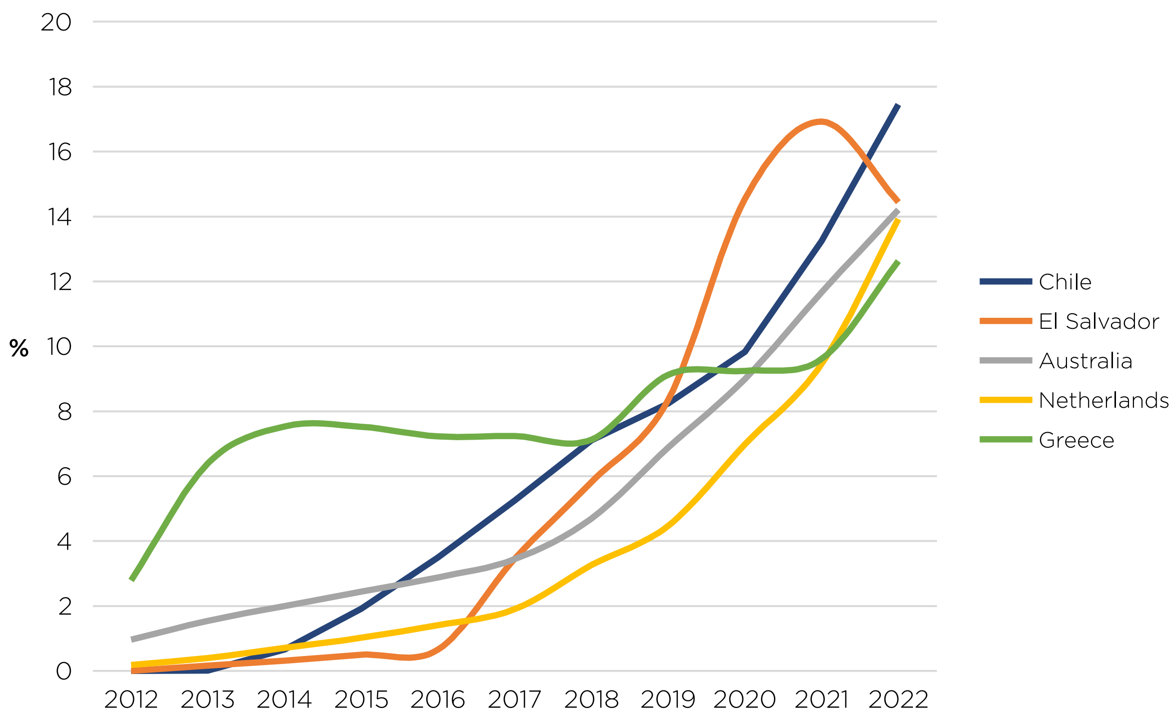


Figure 21: Top 5 countries in share of PV in the electricity generation mix

Source: Ember

3 Countries with an electricity import share surpassing 30% have been omitted from this list, this includes Luxembourg (83%), Lithuania (67%), Moldova (44%), and Latvia (31%). This exclusion is based on the fact that the values present the proportion of solar PV in the domestic electricity generation, rather than the proportion of solar PV satisfying the domestic electricity demand. Consequently, when the share imported electricity is high, a minor solar PV capacity within a country can represent a significant fraction of domestically generated electricity. However, this won't accurately indicate the solar PV's portion in meeting the country's overall electricity demand.

In 2022, Chile was the country with the highest share of PV in its electricity mix. The country pursued its solar expansion and the annual installations above 1 GW over the last two years have led solar PV to cover 17.5% of the nation's total electricity generation. From less than 10% only two years ago, Chile is taking advantages of the generous solar conditions. Indeed, in the northern part of the country, the combination of high altitude, frequent lack of clouds, and comparably low levels of ozone and water vapor, makes the region standing out as an exceptional site on the planet for harnessing solar power. Across much of Chile, the yearly average solar radiation surpasses 2,000 kWh/m^2, and in specific areas and seasons, it can even exceed 10.0 kWh/m^2/day.

El Salvador comes second with 14.5% of its electricity generation covered by PV. The country has experience in large scale projects exceeding 100 MW developed though tenders launched in 2021. As a result, solar PV comes as the second source of renewable electricity in the country, behind hydro which covers 32%. However, a resurgence in natural gas in 2022 has decreased the share of solar PV by 2.5 percentage point compared to 2021's level.

With 14.2% of its electricity generated from solar PV, Australia closes the podium on rank three. The market slowed down in 2022 due to high module prices, but the country managed to maintain a steady and gradual progress by implementing consistent and reliable supportive policies. Notably, the Renewable Energy Target enforces a requirement for a portion of the electricity supply to come from small-scale renewable systems, particularly solar systems under 100 kW. Various support measures are also in place, including feed-in tariff programs, regional aid initiatives such as interest-free loans for residential solar, and grants for large-scale solar projects. The introduction of Renewable Energy Zones (REZ) has opened the door for multi-gigawatt projects, with strong demand seen in recent auctions. While several Australian states have been traditionally very supportive of solar, a change in the federal government has raised hopes for stronger backing from Canberra as well – indeed, the new government promised to turn the country into a "renewable energy superpower". Apart from policy, Australia's abundant solar exposure and high retail electricity prices contribute to the appeal of solar PV for businesses and households that resulted in nearly every 4th home having a solar rooftop system installed end of 2022.

Finally, solar PV is covering 13.9% and 12.6% of the Netherlands and Greece's electricity generation in 2022. The Netherlands uptake has been very steady, mimicking the development of Australia. Both countries started from the bottom in 2012, and now are at the forefront of solar development. While their topographies and demographic conditions are very different from one another, both their markets were heavily supported by rooftop PV. Greece experienced a slight bumpy ride with periods of stagnation in the share of solar PV coverage. Nevertheless, the country progressed by 3 percentage point in a single year, and crossed the 10% mark.

Other notable developments include Hungary, where solar PV generated 4.8 TWh, covering 12.6% of the country electricity generation, and 9.4% of the total electricity demand. The difference lies in the fact that Hungary is importing 25% of its electricity. Cyprus and Germany have also both surpassed the 10% threshold, with 11.6% and 10.2% respectively. While numbers are not available for 2022 in Yemen, the story remains quite impressive. During the civil war, a significant power blackout hit Sanaa in 2015, when the Marib power plant, a key energy source for Yemeni cities, stopped working. This situation led to a surge in the generator market for a period but generators couldn't assure continuous operation due to rising fuel costs and sporadic fuel shortages. Consequently, solar energy became the viable choice for Yemenis and eventually covered 17% of the country electricity generation in 2017. Due to the conflict, it remains hard to evaluate how much of the installed capacity is off-grid.

Many countries across the globe are increasing the share of PV in their electricity mix. During the period 2019-2022, some astonishing development came from Estonia which increased its share of solar PV from less than 1% to over 6%. The Netherlands, Hungary, Cyprus, Ukraine and Portugal managed to triple the amount of solar. . Finally, Chile, Spain, and Australia also doubled the share of PV in their electricity mix in the same time span. This list includes only countries with a PV share higher than 5% in 2022; several other countries across the globe are rapidly growing their share of PV in their electricity mix.

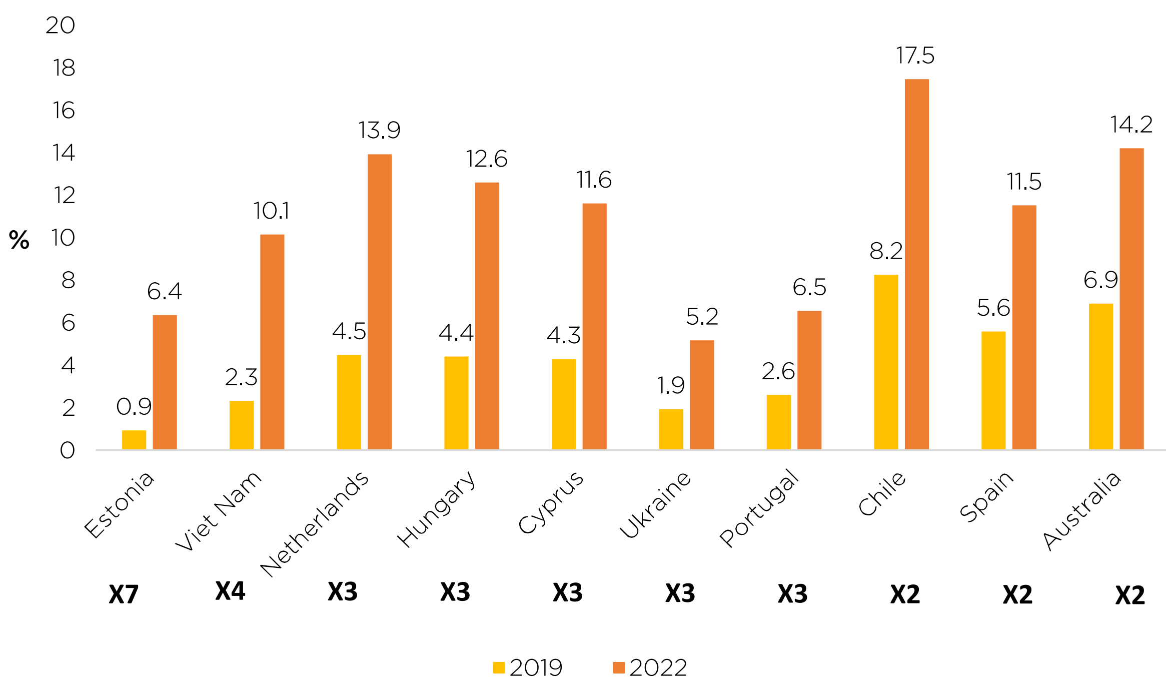


Figure 22: Largest increase in share of solar PV electricity generation from 2019 to 2022

Source: Ember

The adoption of solar PV shows a relatively uniform pattern across regions. In 2022, solar PV contributed to 5.1% of electricity in the APAC region. Following closely, Europe reached 4.8% (7.3% for EU27). Meanwhile, the Americas achieved 4.1%, and both the Middle East and Africa shared a similar standing of 1.7%.

3.2. Solar Thermal

3.2.1. Concentrated Solar Power

Year 2021 was the first year to witness a decrease in Concentrated Solar Power (CSP) global installed capacity following the decommissioning of the Californian Solar Energy Generation Systems (SEGS) in July 2021. The decrease followed a standstill trend since 2015, primarily due to Spain and the United States, the two major players in this industry, who ceased to expand their capacity during this period. The main reasons behind this stagnation were the much lower capital costs of solar PV technologies and a deficiency of supportive policies for CSP.

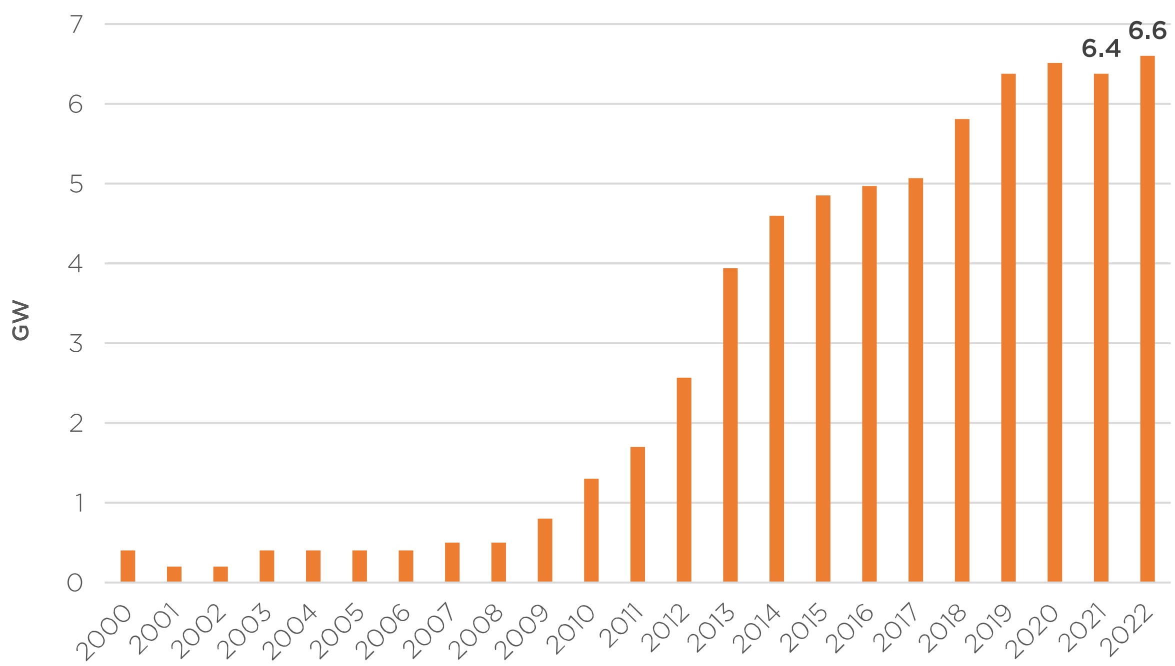


Figure 23: Cumulative CSP installed capacity 2000-2022
Source: IRENA

However, in 2022, new players took the lead and the total installed CSP capacity increased from 6.3 GW in 2021, to 6.6 GW in 2022. The new installations in the United Arab Emirates (UAE) and China are responsible for all the increase. In the UAE, the first part of a hybrid CSP Mohammed bin Rashid Al Maktoum Solar Park plant became operational with a capacity of 200 MW. Upon its full completion the project's capacity will reach 700 MW, comprising of a 100 MW concentrated solar tower and a 600 MW parabolic basin complex, and will become the world's largest CSP facility. Nevertheless, most of the future new capacity is expected to come online in China. At the end of 2022, the country had at least 30 CSP projects in diverse phases of construction and commissioning. Among these, 14 projects are expected to become operational in 2023. The 14th Five-Year Plan (2021-2025) also emphasizes on the proactive advancement of CSP and encourages the integrated establishment of CSP, wind, and PV in regions such as Gansu, Inner Mongolia, Qinghai, and Xinjiang. In Western regions of China, where solar irradiation is abundant, the adoption of CSP to meet the peak demand is highly encouraged. Most of the companies active in the industry are currently based in China, and the United Arab Emirates, which reinforces the idea of seeing new projects to emerges in those regions.

An additional area which can further boost the development of CSP around the globe is the retrofitting of coal plants with CSP and thermal energy storage. The technology would allow to transform coal-fired plan into large-scale thermal energy storage systems to store curtailed intermittent renewable energy and act as low-cost thermal batteries. In countries with high direct irradiation, CSP has the most potential to replace fossil fuels for Industrial Process Heat (IPH). The sector, which is almost entirely dependent on fossil fuels at this time, consumed more than 38% of the total global energy and was responsible for 26% of the global CO_2 emissions in 2020. time. Decarbonization of the industrial process heat sector is vital for accomplishing emission reduction objectives and offers the potential to replace fossil fuels with solar thermal systems and thermal energy storage. Nearly half of the IPH demands fall within the low to medium temperature range (<260°C), and several existing solar technologies are well-suited for these purposes. These include solar ponds, evacuated tube collectors, parabolic troughs, parabolic dishes, and central receiver towers.[4]

Solar Thermal Heating

According to the International Energy Agency's Solar Heating & Cooling Programme (IEA-SHC), the global solar thermal heating market was estimated to have reached 542 GWth by the end of 2022. This figure reflects a 4% increase compared to 2021, resulting in a net gain of 19 GWth. In the context of energy generation, the collective solar thermal fleet contributed to a total energy production of 442 terawatt-hours in 2022.

4 D. Goswami, Y. (2022), Decarbonizing industrial process heat is essential to achieving net-zero goal, Solar Compass 3-4: 100028.

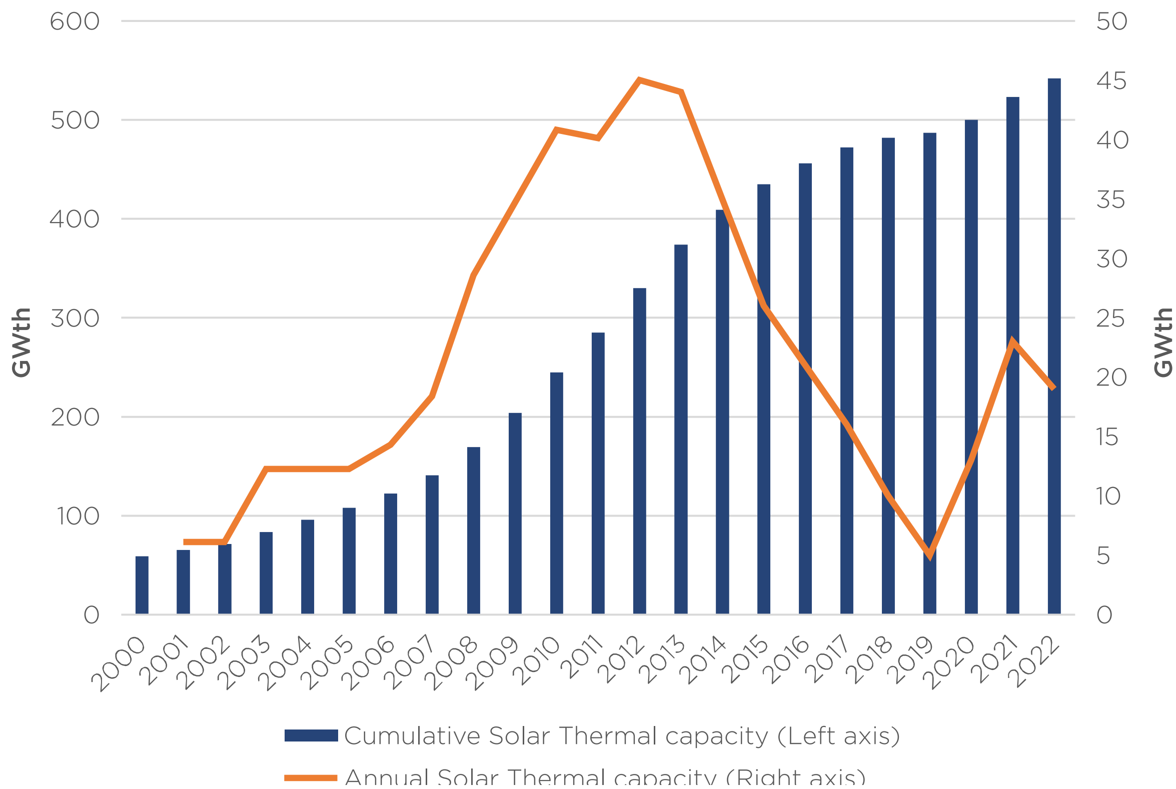


Figure 24: Cumulative and annual solar thermal capacity 2000-2022
Source: IEA-SHC

While the total fleet continue to grow, the yearly net addition showed a mixed picture. Following seven year of consecutive decline from 2012 to 2019, the global solar thermal market development recovered in 2019-2021, but declined by 9.3% in 2022, from 23GWth to 19 GWth. This slump is mainly explained by a reduction in the market of the two solar thermal giants, China and India whose market decreased by 12.4% and 21% respectively as a late consequence of COVID-19 restrictions and the competition with solar PV. Similarly, other nations that have traditionally shown strength in this sector have experienced decrease in their annual installation such as Australia (-7%), Austria (-16%), Brazil (-2%), the Palestinian Territories (-4%), Spain (-5%), and Turkey (-4%).

Nevertheless, this should not overshadow positive developments around the world, especially in the Middle East and Europe, with annual growth rate reaching up to 145% for Lebanon. The increasing price of electricity and the depreciation of the currency have incentives Lebanese consumers to purchase solar thermal to avoid relying on electricity for heating purpose. In Europe, Italy (+43%), France (+29%) Greece (+17%), Poland (+11%) and Cyprus (+5%) all pursued positive developments and South Africa remained the leading Sub-Saharian market with a annual 9% market growth.

Global Solar Deployment Scenarios

This chapter provides an in-depth analysis of an assortment of scenarios depicting future developments 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 examined the forecast provided by a selection of chief solar market analysts, including 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 Global Commodity Insight (S&P Global), the European PV industry association SolarPower Europe (SPE) as well as long-term energy modelling research groups from academia.

Predicting the trajectory of solar markets poses a formidable challenge, as numerous variables can influence its direction. These factors extend beyond alterations in policy frameworks or technological and cost improvements. They also encompass macroeconomic forces that transcend the solar realm.

One clear example is the Russian invasion of Ukraine, which created a chain reaction that utterly changed the global energy landscape. Many regions around the world have experienced skyrocketing prices that have severely impacted consumers, all against an extremely tense geopolitical configuration with energy security at its core. What's more, the world's overreliance on fossil fuels, with its associated price and resource volatility, has come into the public debate and has intensified the need for an accelerated energy transformation. This event has had a major impact on the deployment of solar and has reinforced solar as the leading technology for the energy transition. The global solar market is rapidly expanding, yet it can be subject to volatility. For this reason, even in short-term scenarios, solar analysts' forecasts present considerable divergences. This inherent uncertainty is magnified when extending the temporal horizon to the medium and long term.

Nonetheless, and despite differences in estimations among agencies, certain patterns tend to be established based on market dynamics, forecasting trends, and more. Looking back in time to previous studies provided by the World Energy Outlook (WEO), the IEA's flagship report, it is evident that solar PV deployment has been consistently underestimated (see Fig. 25). While the global solar fleet surpassed the terawatt threshold in 2022 (1,143 GW) of installed capacity, latest estimation curves are still downplaying the potential of solar despite a display of a hockey-stick growth trajectory. Forecasts have continuously been upwardly revised but the size of the existing gap remains wide. The total installed capacity in 2022 was already higher than what the IEA's Net Zero Emission (NZE) Scenario by 2050 study expected it to be in 2025.

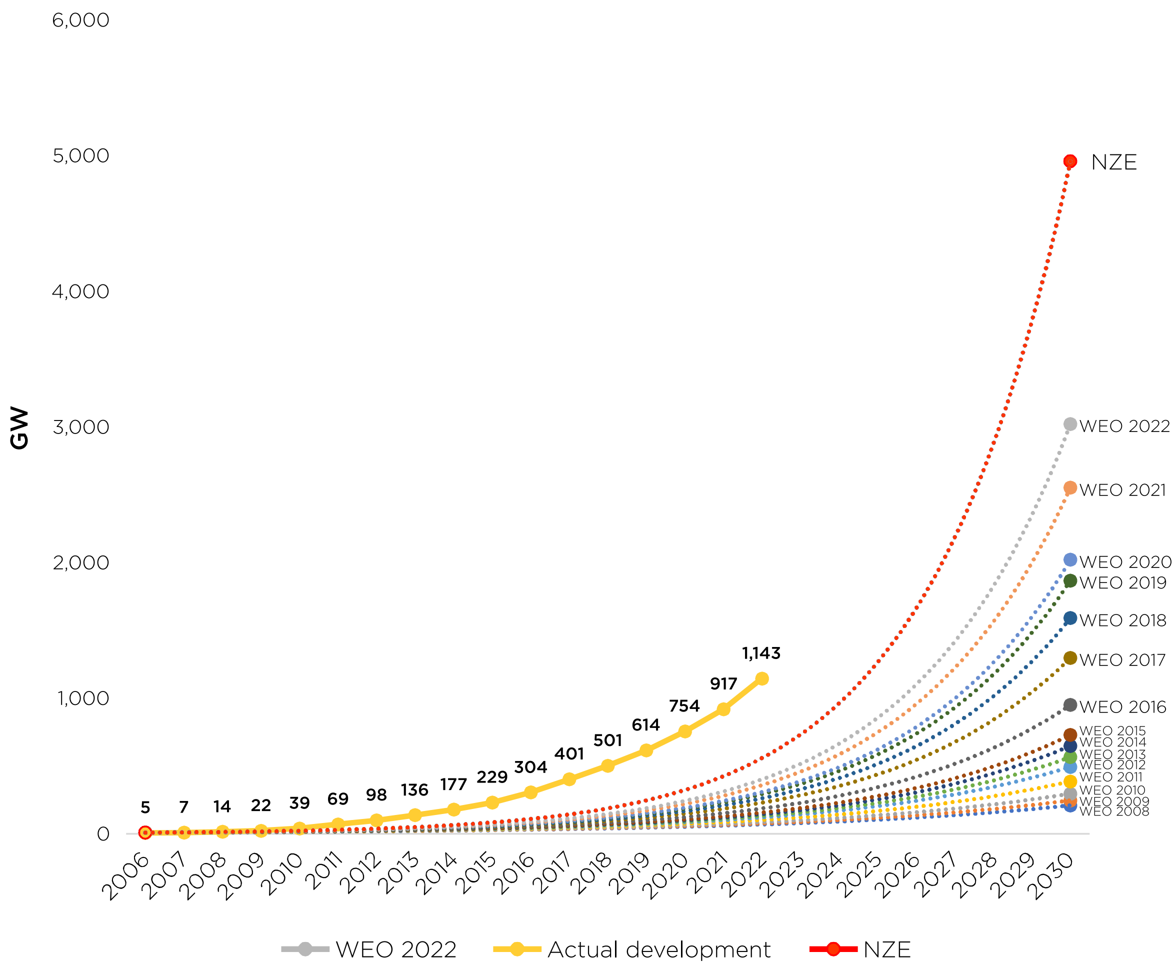


Figure 25: IEA World Energy Outlook forecasts versus actual historical development of solar PV

Source: IEA (note on scenarios considered: WEO 2008 and WEO 2009 are 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 226 GW of grid-connected capacity added in 2022, the world's solar market is forecasted to expand by 118% to reach 493 GW by 2025 (Fig. 26). This figure represents the average growth expected by different research agencies on solar developments, although individual forecasts differ from the mean. At the lower end of the range, the IEA still stands as the most conservative forecasting data centre. In its latest Renewable Energy Market Update – June 2023, the agency revamped upwards its estimations to 308 GW to be built in 2024, 33% higher than their previous evaluation. However, at the time of writing this report, the IEA had not yet disclosed their adjusted forecasts for 2025 and onwards, and hence, no data was included for 2025.

Closer to but somewhat below the average estimate, SolarPower Europe's Global Market Outlook 2023-2027 (GMO 2023) Medium Scenario foresees 462 GW to be installed in 2025 equivalent to an 105% increase compared to 2022 levels. Then, at just 2 GW above the average estimate, the agency S&P Global revised upwards their projections for solar PV and expects the global solar fleet to augment to 495 GW in 2025 (+119%). Finally, standing 28 GW above the average, BNEF's Global PV Market Outlook 2023 central scenario presents the most optimistic stance for 2025 deployment levels as the agency predicts 521 GW of solar PV to be rolled out that year (+131%).

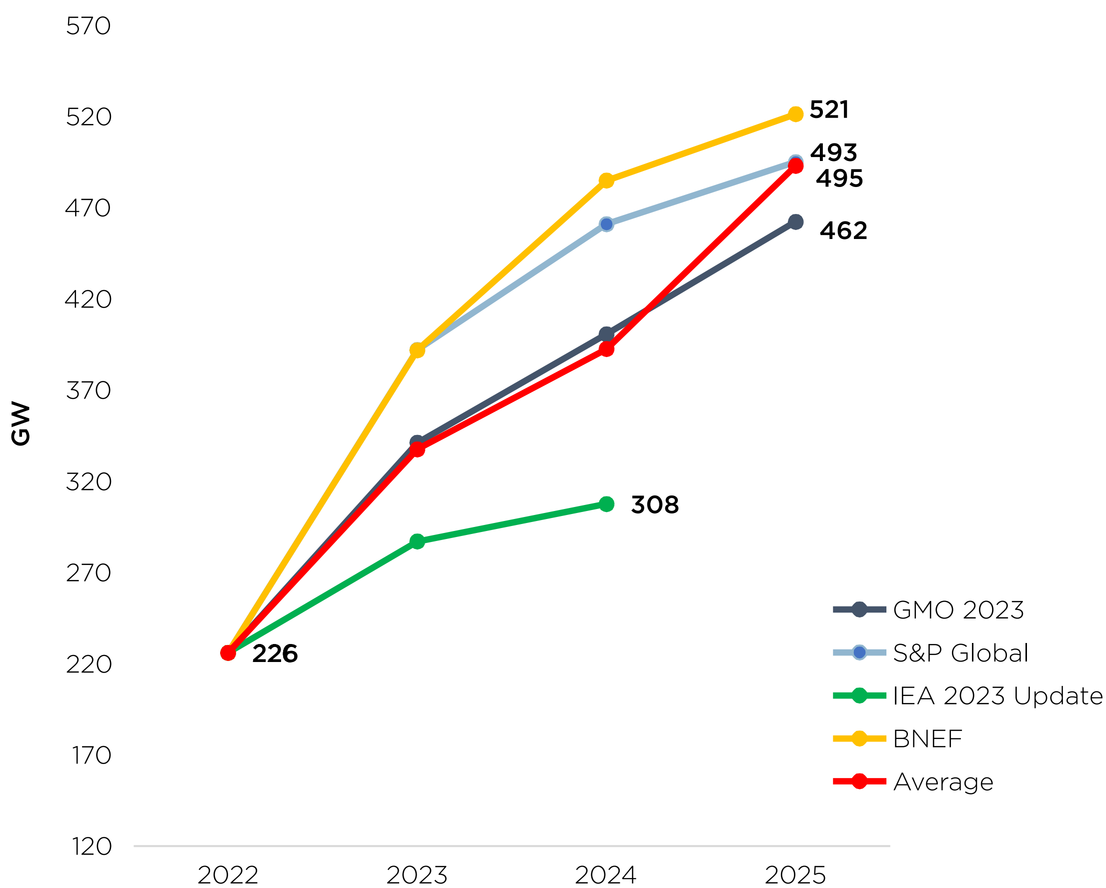


Figure 26 Average installed capacity scenario in 2025

Source: IEA, BNEF, S&P Global, SPE

The cumulative scenarios for 2025 are closely tethered to the differences in the annual market scenarios (see Fig. 27). SPE's GMO 2023, S&P Global and BNEF expect the total operating PV capacity to surpass the 2 TW threshold (more precisely, 2,381, 2,560 and 2,622 GW respectively) by 2025. This would entail more than doubling the existing global solar market in less than 4 years, considering that the TW milestone was reached in April 2022. On average, it is expected that 2,521 GW will be installed worldwide by the end of 2025. SolarPower Europe's figures stand below the mean despite projecting more than 2.3 TW of cumulative installations.

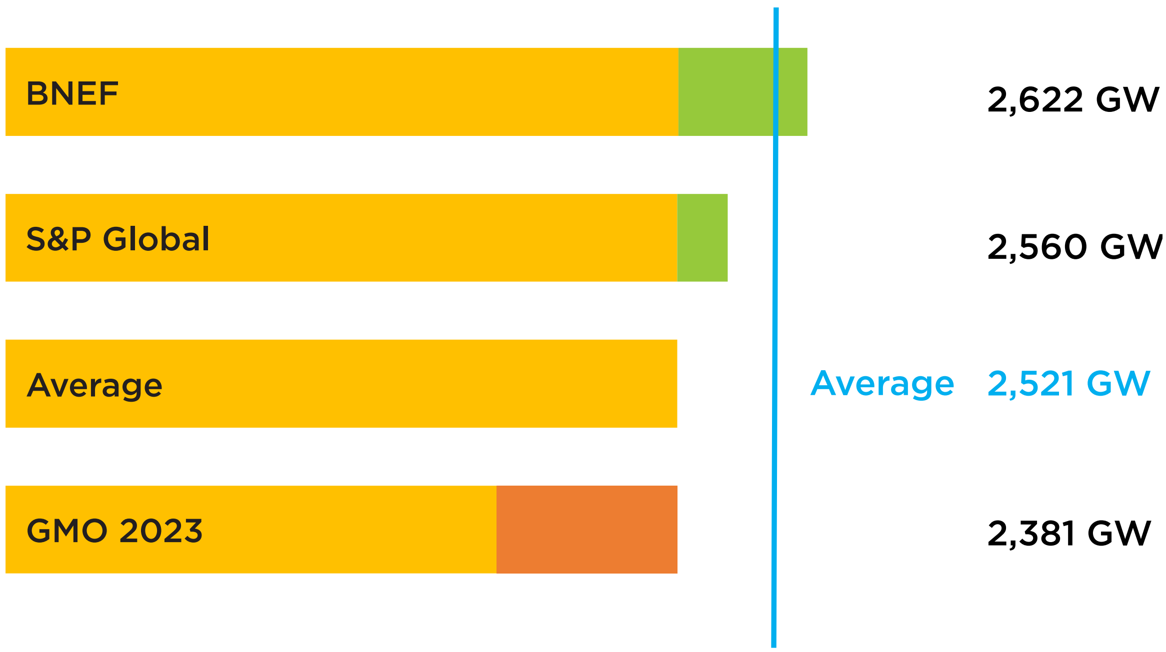


Figure 27 Cumulative installed capacity scenarios in 2025
Source: BNEF, S&P Global, SPE

Figure 28 displays the evolution of the regional distribution of total installed solar PV capacity in the timeframe 2022-2025 under SolarPower Europe's Low, Medium and High Scenarios from GMO 2023. As can be observed, and despite the growth in absolute terms, the geographic allocation of solar PV capacity is expected to remain stable in all three scenarios. The APAC region, which in 2022 absorbed around 56% of the solar grid-connected fleet, would see its global share slightly decrease over the coming years to around 58% in 2025. Europe, currently at 25%, would remain second, although it would lose 4-5 percentage point, while to the MEA region is expected to increase from 2% in 2022 to 4-5% in 2025. The Americas will retain the third position as its share will remain constant at 16-17% in 2025.

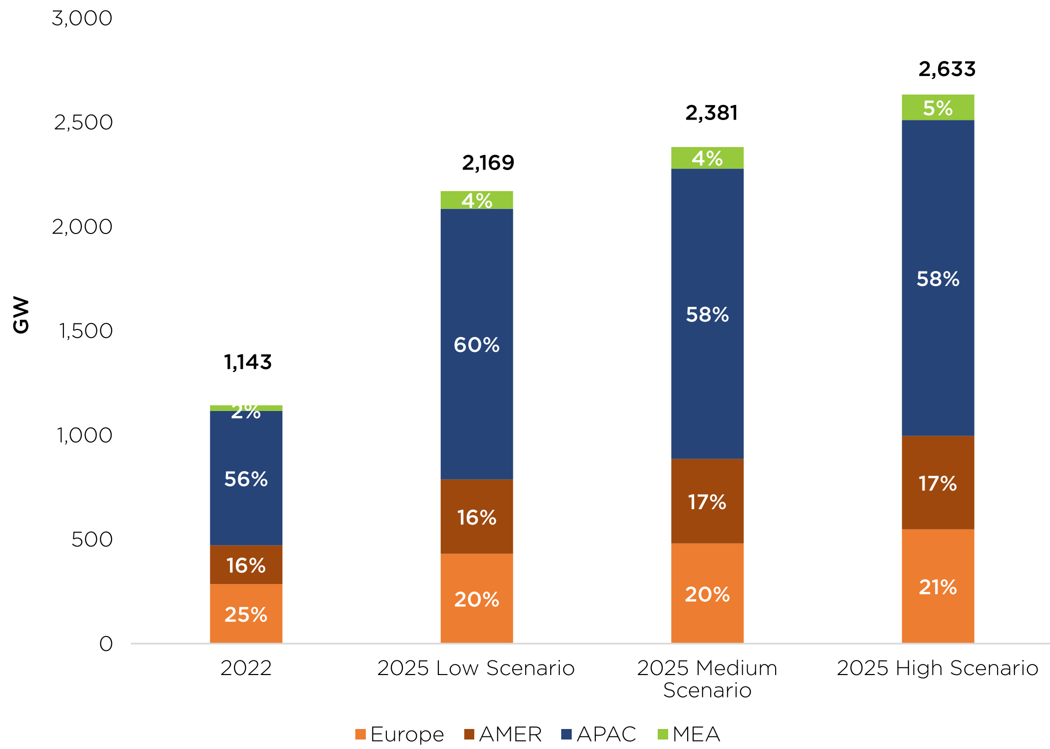


Figure 28: Total solar PV installed capacity by region, 2022 and 2025
Source: SPE

4.2. Medium term (2030)

Longer-term forecasting is a difficult endeavour, as extended timeframe estimations cannot rely on current market dynamics and predictable policy and regulatory trends. As a result, the magnitude of the error may increase over time, as uncertainty augments. For this reason, only a limited number of medium to long-term forecasts are available. To overcome the challenge, the studies utilised in the analysis use a top-down approach based on climate and energy objectives in the long term (2050), most of them setting 2030 as an intermediate milestone. This provides a stable framework which then can be utilised to develop the myriad of paths that may or may not lead to it.

The intermediate-term assessment includes the academic research from LUT University in Finland and Australia's University of Technology Sidney (UTS), which are among the scholar institutions whose energy modelling groups have conducted studies on the transition to 100% renewable energy systems at the global scale. LUT carries out a cost-optimisation modelling grounded on the objective of reaching 100% renewable energy by 2050, determining cost-efficient routes to realise this target. UTS, in close collaboration with the German Aerospace Center (DLR), applies a simulation technique for long-term energy system modelling, whereby pathways to global 100% renewable systems with a focus on technological diversification are studied. A third scientific paper from Stanford University examines global 100%

renewable energy systems in 2050 but does not develop potential pathways from the current state of play. Rather, it supplies an innovative optimal 100% renewable system in 2050. Consequently, the study is not included among the medium-term scenarios but considered in the long-term scenario assessment[5].

A second selection of studies that are taken into account in this section comes from non-academic agencies, including the International Energy Agency, the International Renewable Energy (IRENA), and energy consultant BNEF. Diverging from academic studies, these studies do not model 100% RE systems by 2050 but have other long-term objectives. The IEA's study NZE 2050 Scenario from its latest update on the NZ Roadmap report aims to limit GHG emissions to reach a carbon-neutral economic system, while IRENA's 1.5°C Scenario from the World Energy Transition Outlook 2023 has the ambition to comply with the 1.5°C goal from the Paris Agreement. BNEF's NEO 2022 offers a roadmap for meeting the Paris Agreement and achieving net-zero emissions by 2050. An overview of the scenarios included in the medium and long-term analysis is provided in Table 5.

5 For a review of net-zero emissions and 100% renewable study, see : S. Renné, D. (2022), Progress, opportunities and challenges of achieving net-zero emissions and 100% renewables, Solar Compass, Volume 1, https://doi.org/10.1016/j.solcom.2022.100007.

Table 5 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	Yes	Yes
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	Yes	Yes
Stanford	Low-cost solutions to global warming, air pollution, and energy insecurity for 145 countries	Academic	100% WWS	2022	100% RE by 2050	No	Yes
IEA	Net Zero Roadmap: A Global Pathway to keep the 1.5 °C Goal in Reach	Intergovernmental	NZE	2023	Net-zero emissions by 2050	Yes	Yes
IRENA	World Energy Transitions Outlook 2022-23	Intergovernmental	1.5°C Scenario	2022 & 2023	Meet Paris Agreement at 1.5°C by 2050	Yes	Yes
BNEF	Global PV Market Outlook (2030) & New Energy Outlook 2022 (2050)	Consultant	Net Zero Scenario	2022	Meet Paris Agreement, net-zero emissions by 2050	YES	Yes

Figure 29 illustrates global solar PV installed capacity in 2030 according to the long-term scenarios described above. In all scenarios analysed, solar PV capacity augments from the 1 TW installed in 2022 to more than 5 TW in 2030. In its latest update of the NZ Roadmap report, the IEA updated its predictions for solar very significantly, leaving in the past any doubt that the agency could bear on solar being the market leader of the energy transition. As it can be observed, the IEA anticipates a total of 6.1 TW to be grid-connected by 2030, surpassing the figures from BNEF and IRENA. The former, is predicted a total installed capacity of 5.8 TW, while IRENA expects 5.5 TW to be installed by 2030. The fifth scenario is considerably more ambitious, with 10.21 TW of PV rolled out worldwide by 2030. Thus, LUT's scenario predicts an approximate doubling of the solar capacity installed by 2030 relative to the other four scenarios. On the side of the spectrum, the UTS scenario anticipated just over 5 TW to be installed by 2030.

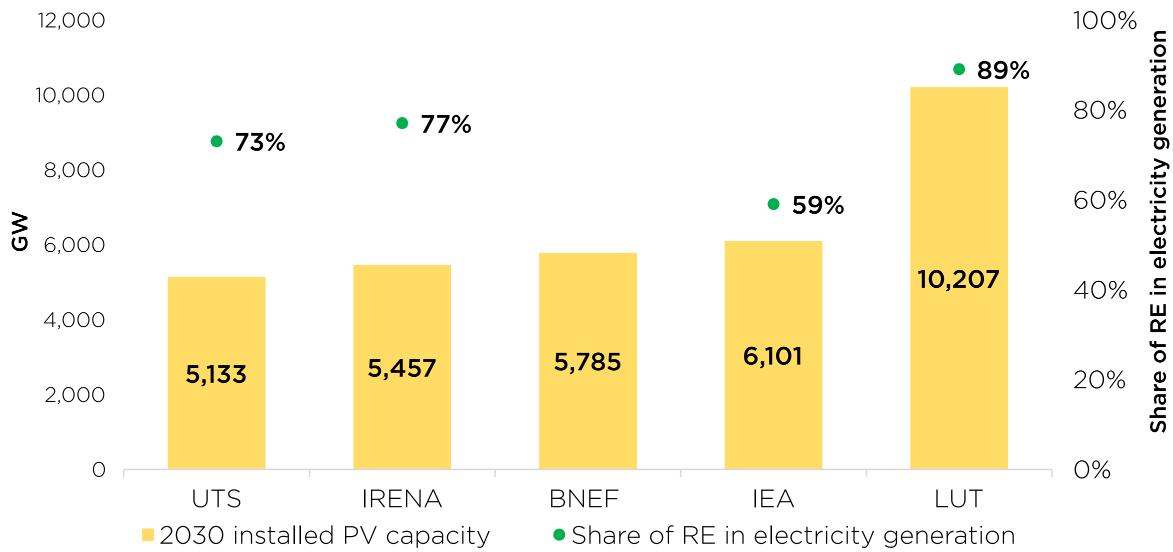


Figure 29: Scenarios for total installed capacity of solar PV in 2030
Source: BNEF, UTS, IRENA, IEA, LUT

Deviations in the scenarios can be linked to a set of factors. One fundamental component is the level of ambition towards the penetration share of renewable energy in the power mix. As can be observed in the previous figure, there exists a positive correlation between the RES share in electricity generation and the deployed PV capacity. For instance, the IRENA scenario presents the second highest RE penetration in electricity generation (77%) and the fourth-highest deployed capacity (5.5 TW) while the LUT scenario achieves the largest renewable penetration in the grid (89%) and the highest deployment figure (10.2 TW). The IEA in turn, forecasts a relatively low penetration of renewables by 2030 (59%), but still projects solar capacity to surpass the 6 TW threshold by the end of that year. This is due to the fact that the agency anticipates solar to absorb 38% of the total renewable deployed capacity (wind, the second leading technology, would accumulate 17%).

Although notable differences in estimations arise and some modelling results may appear to be very large – especially LUT – the historical tendency has been to underestimate the deployment pace of solar PV, and market

developments from last years illustrate the contrary. When looking at the learning curve in Figure 30, solar PV additions almost double every three years. At this pace of progress, the TW-size annual market is reached before 2030.

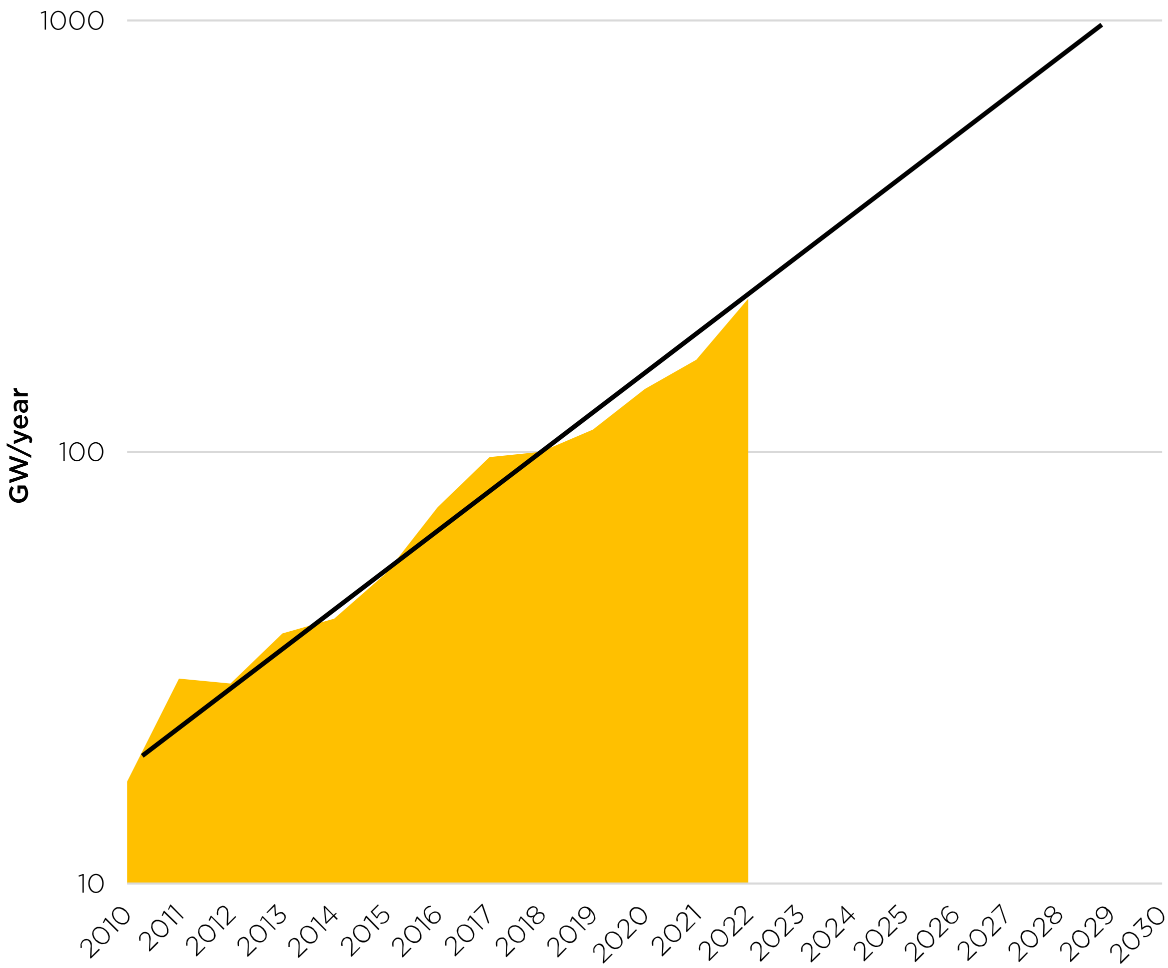


Figure 30: Solar PV learning curce - Toward a 1 TW annual global market by 2030
Source: SPE, IEA, IRENA, BNEF, S&P Global

Out of the five mid-term scenarios taken into consideration, the UTS, IRENA´s 1.5°C Scenario from the World Energy Transition Outlook 2022[6], and LUT provide market insights on the regional breakdown of PV installed capacity by 2030 (Figure 31). Despite some parallelisms between the three scenarios, the LUT scenario differs from the other two. The UTS and IRENA scenarios foresee a notable change in the shares of regional distribution compared to 2022. Although the APAC region still dominates the global solar market, its relative share decreases from 56% in 2022 to 49-50%, equals 2.5-2.6 TW. In both scenarios Europe loses its second place, decreasing its relative share from 25% to 14-17% (715-892 GW). That market share difference is taken up by the Americas (#2 rank) and the MEA (#4 rank). The latter would see its share sizably increased from 2% in 2022 to 8-13% in 2030 (402-703 GW), while the former would gain market share from 16% in 2022 to 23-26% in 2030 (715-892 GW).

The LUT's scenario on the contrary, anticipates that both APAC and AMER retain their PV

6 Due to the fact that the WETO 2023 does not disclose any data on future regional developments of solar PV, last year's report WETO 2022 had to be used for the regional analysis of deployment levels by 2030.

market share in 2030, with a slight increase by 1% to 57% (5.7 TW) and an increase by 2% to 18% (1.8 TW) respectively. The important difference in this scenario is that MEA´s expanding market share from 2% to 11% mostly at the expense of the European market share, which drops from 25% 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 rank, being surpassed by the AMER region. APAC remains the largest solar market and MEA the smallest.

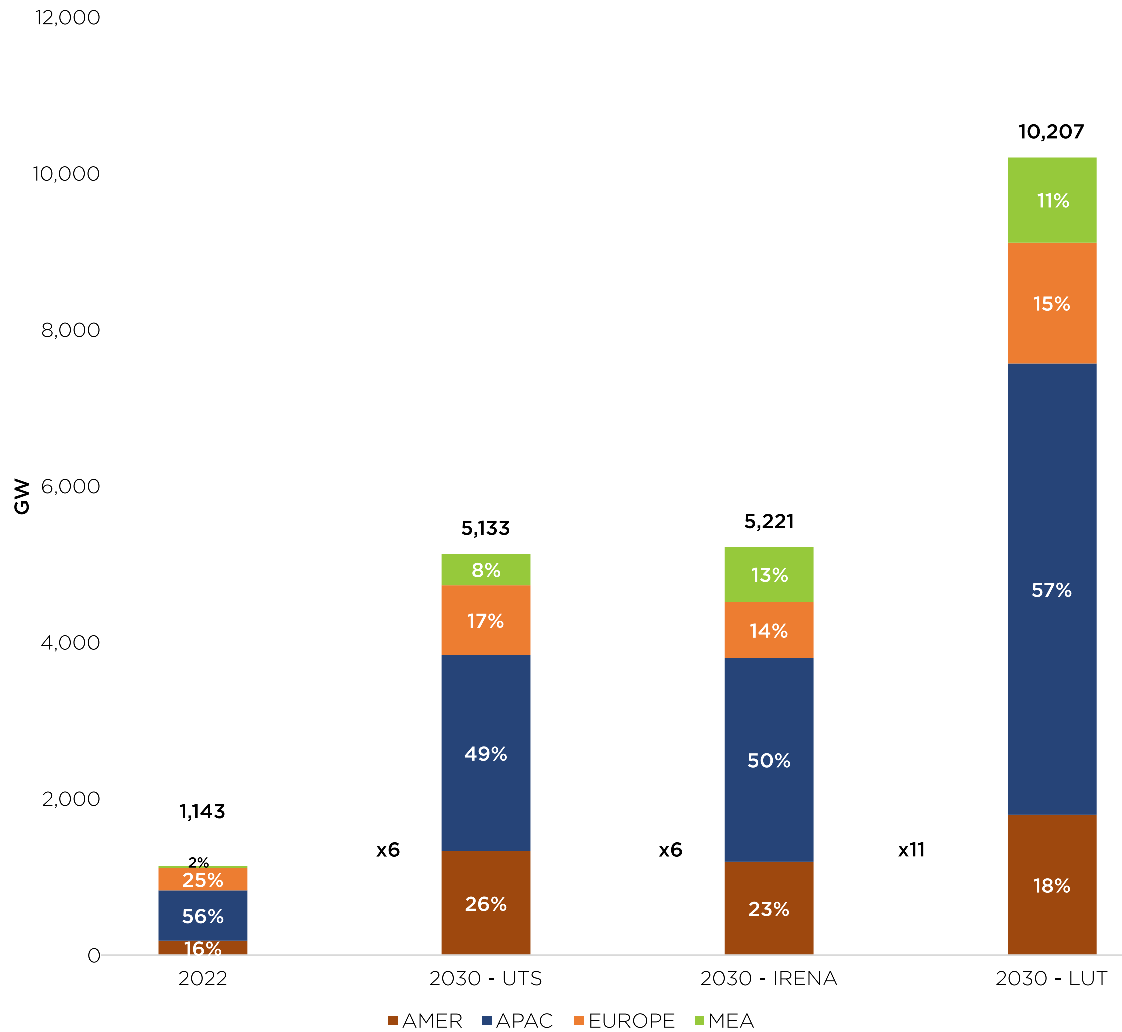


Figure 31: Regional distribution of total solar PV in 2030
Source: SPE, UTS, IRENA, LUT

As a part of their analysis, three research groups, namely the IEA, IRENA and UTS, also model the future developments of CSP capacity by 2030. This technology plays an important role in the analysis of scenarios as certain studies (like the UTS one) opt for a larger diversification in energy sources by 2030 and 2050. Figure 32 displays the predicted growth for the technology according to the three scenarios proposed in the respective studies. At the most optimistic end of the spectrum, the UTS anticipates that the total installed capacity for CSP will expand by elevenfold to 474 GW relative to the total fleet of 6.6 GW in 2022 , following the assumption of a more diversified energy system by 2030. In the middle of the range, IRENA's 1.5°C scenario expects an increase of 38 times to reach 247 GW in 2030 relative to 2022, while the IEA estimates a total of 73 GW to be built by the end of the decade.

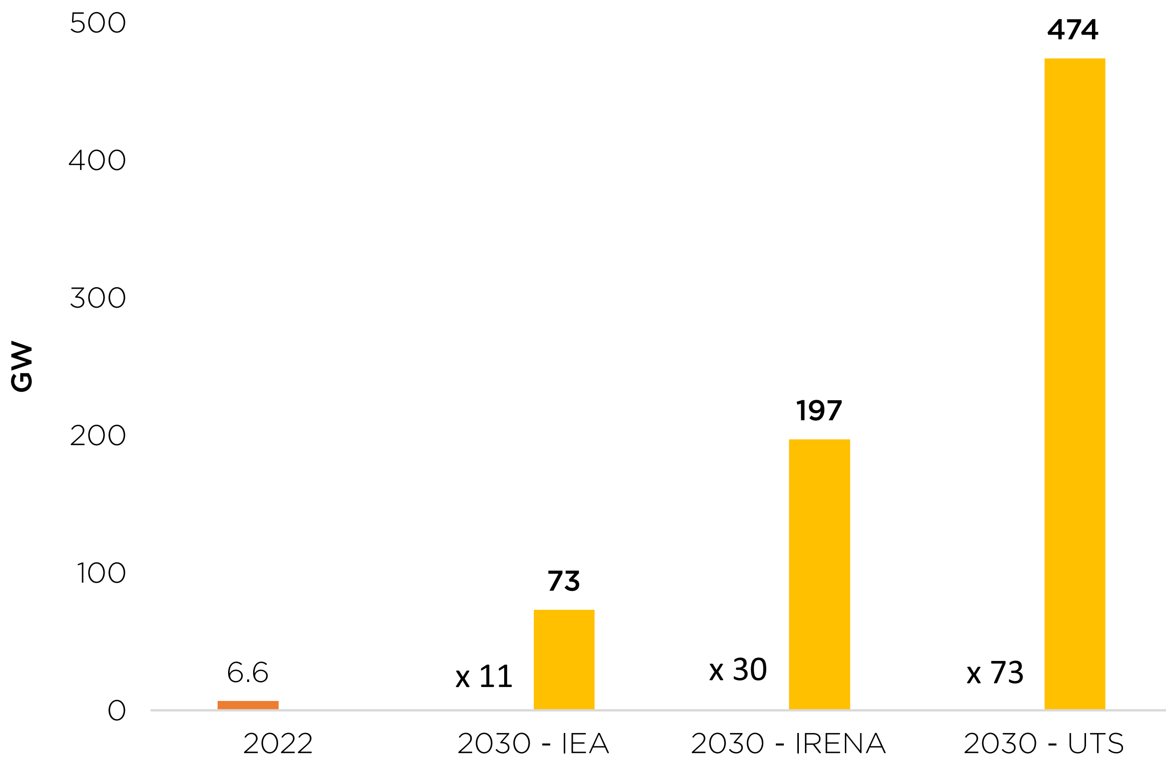


Figure 32: Total installed CSP capacity by 2030
Source: IEA, IRENA, UTS

4.3. Long term (2050)

While the previous section analysed solar PV deployment scenarios for 2030, this section examines an outlook of long-term forecasts of deployment utilising 2050 as the target year for achieving global climate goals. For this distant-horizon assessment, all the studies presented in the 2030 section are included, with the addition of the scenario provided by Stanford University's energy modelling group. In line with the rest of the research groups, the Stanford scenario outlines the pathway required to achieve the objective of a 100% renewable energy system by 2050. Although the study marks a significant milestone for renewable energy shares in 2030, data on solar deployment levels is not publicly accessible, and as a result, this research was not included in the previous section.

Figure 33 presents long-term deployment scenarios for solar PV in 2050, which range between 63.4 TW from LUT University to 12.7 TW predicted by the UTS. The second largest operating capacity would total 25.6 TW according to Stanford, followed by IEA's prediction of 18.7 TW installed by 2050. Below, IRENA's 1.5°C Scenario foresees 18.2 TW to be totally deployed by 2050, while 1.5 BNEF's Net Zero scenario expects the solar global operating fleet to reach 16.9 TW.

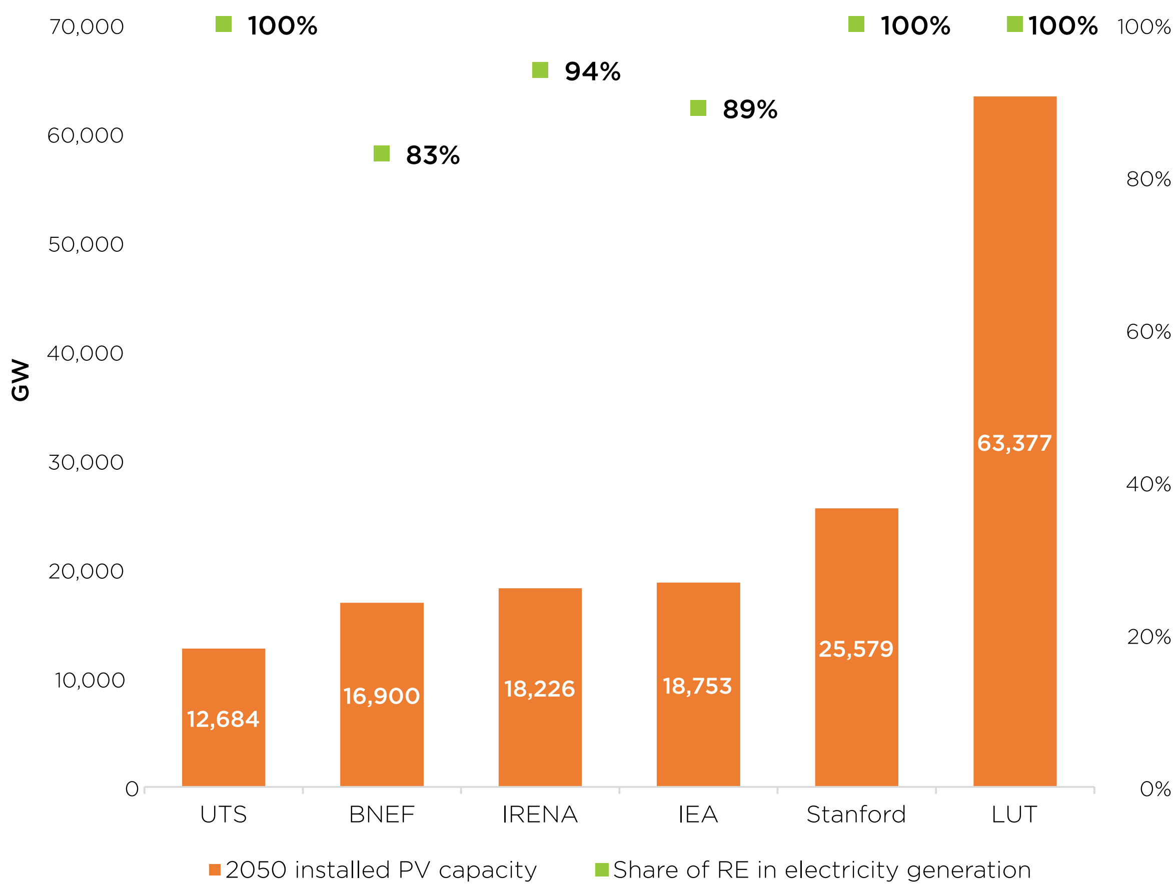


Figure 33: Scenarios for total installed capacity of solar PV in 2050

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

This wide range of estimations can be attributed to several diverse factors, including the level of ambition in each of these different scenarios, the methodology utilised, the scope and the type of model that was applied, the degree of technology diversification and cost assumptions, and other independent parameters that can exert a significant impact on the scenario results.

The first important distinctive feature to take into account is the ambition level that would guide solar developments until 2050. As previously introduced, the energy system modelling from UTS, Stanford and LUT target an energy system that is 100% renewable, whereas the IEA, BNEF, and IRENA assume a lower level of renewable energy supply, with RE shares standing at 80%, 83%, and 94% respectively. These existing power supply gaps are considered to be met with the use of fossil fuels combined with carbon capture and storage (CCS) and nuclear energy, which would limit the deployment of renewables. Similarly, research groups diverge on the amount of greenhouse gases that need to be abated to comply with the objectives stated in the Paris Agreement and the potential of carbon sinks to store fossil emissions.

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. Though very much at the beginning, the growing demand for Power-to-X solutions aimed at reducing carbon emissions in hard-to-abate sectors like aviation, maritime, and energy-intensive industries will increasingly the installation of solar and wind energy 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 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.

Cost reduction curves also play a key role, in combination with the array of renewable energy sources selected to meet future energy demand. In global 100% RE studies, different assumptions on the cost trajectory for wind and solar can either outcome a solar or a wind-dominated energy system. In addition, other capital cost assumptions concerning batteries, electrolysers, as well as other non-RE technologies such as CCS[7] can significantly impact modelling results.

Furthermore, as touched upon above, variation also exists among 100% RE scenarios. The LUT scenario in which low-cost solar, batteries, and electrolysers propels the demand for PV electricity, results in a 76% share of PV in the 2050 global energy mix. The Stanford scenario, which favours wind, results in a PV share of 19% by 2050. The UTS scenario lands somewhere in the middle, with 45% of solar PV share in the world energy system by 2050. In this scenario, and despite solar having the lowest capacity volume to be deployed in absolute terms, the role of solar is fundamental in the modelling.

The results of these scenarios can also be examined by assessing the annual PV installation levels mandated to comply with the 2050 goals. The IEA scenario expects 625 GW of solar PV annually added to the grid by 2030, up from 239 GW grid-connected in 2022 (+161%). However, the agency expects the market growth to slowdown after 2030 (23% of cumulative annual growth rate (CAGR) until that year), and to start declining until 2050 (CAGR of 7.9%). Under IRENA's 1.5°C Scenario, the global installed solar PV capacity would increase to 615 GW on average out to 2050 to reach the 18.2 TW of installed PV capacity. The LUT simulation anticipates about 3 TW of annual PV installations in the 2040s, a volume that has been taken up among solar PV experts, as the supply of PV technology more than doubles actual demand, and projections indicate that this gap can be maintained in the future.

All the academic research papers that have been integrated into this analysis were selected based on data availability and prominence in the international energy modelling arena. However, many other scholars have explored the pathways to a 100% renewable-based global energy system and the role that solar PV would have to play in this paradigm. The review provided in Figure 34 presents the weight of solar PV in terms of absolute electricity generation in 2050[8]. The list of studies comprised in the graph below, filed by publication date, includes investigations dating back to 1996. However, the majority have been published within the last 5 years, as energy modelling capabilities have been greatly refined in recent years. The result is a holistic vision of the transition towards a global net-zero energy system that can limit global warming to 1.5°C. As can be seen, all the advanced resource-optimised energy system models generally outcome a predominance of wind and solar in the electricity supply of around 90%. Moreover, all of the studies with solar PV shares above 60% take into account the steep decline in the cost of the technology over time. On the contrary, reports with lower shares of solar PV normally assume a more profound cost reduction in wind relative to solar, or add other technologies to the mix like CSP or bioenergy.

7 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.

8 Breyer and al. (2022), On the History and Future of 100% Renewable Energy Systems Research, IEEE Access (Volume 10), DOI: 10.1109/ACCESS.2022.3193402

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.

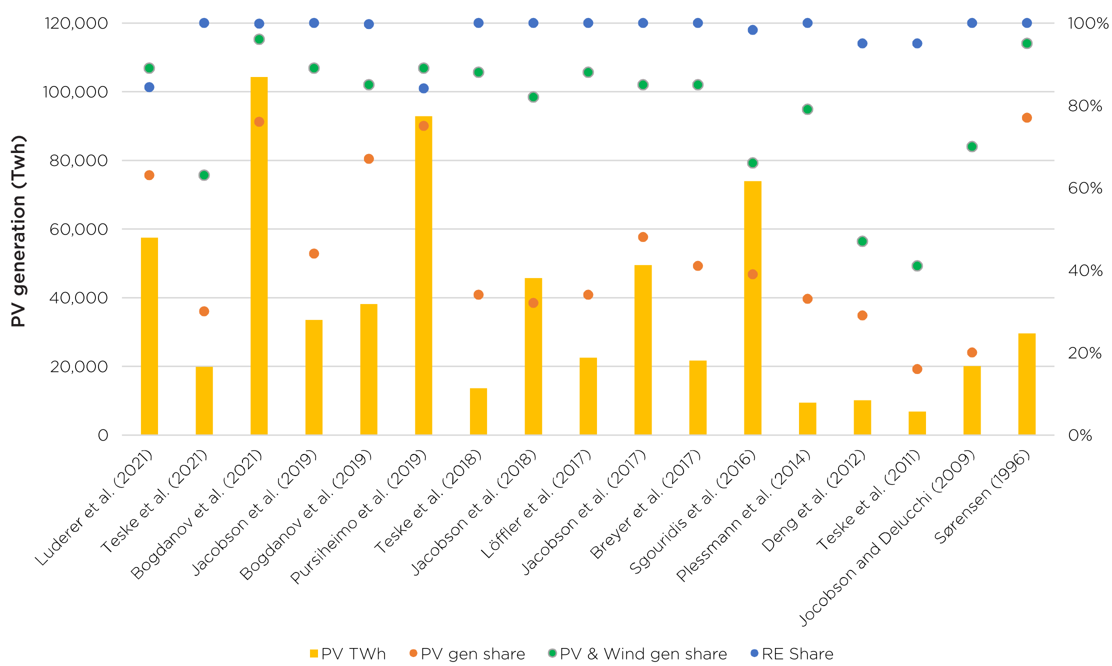


Figure 34: PV generation in global 100% RE system analyses

Source: IEA, IRENA, UTS

Overall, and despite the significant differences arising from the academic analyses and other organisations presented in this long-term forecast overview, the key conclusion to be extracted is that solar PV will play a prominent in the future supply of energy, with a gigantic expansion of installation figures compared to today. According to the six scenarios inspected, from the single TW milestone achieved in early 2022, global solar capacity is predicted to increase between 12 and 63 times in the coming three decades.

When calculating the Watt per capita (Figure 35), the scenarios under consideration reflect between 1,294 and 6,467 W/c to be deployed at the global level by 2050, based on the assumption that the global population will stand at around 9.8 billion that year. Even if they take on the most conservative estimation, 2022's figure of 144 W/c should increase by nearly 9 fold to achieve the UTS scenario. This also means that even in the least ambitious scenario, the world on average would surpass Australia, the country with the highest solar penetration per inhabitant in 2022 (1,191 W/c).

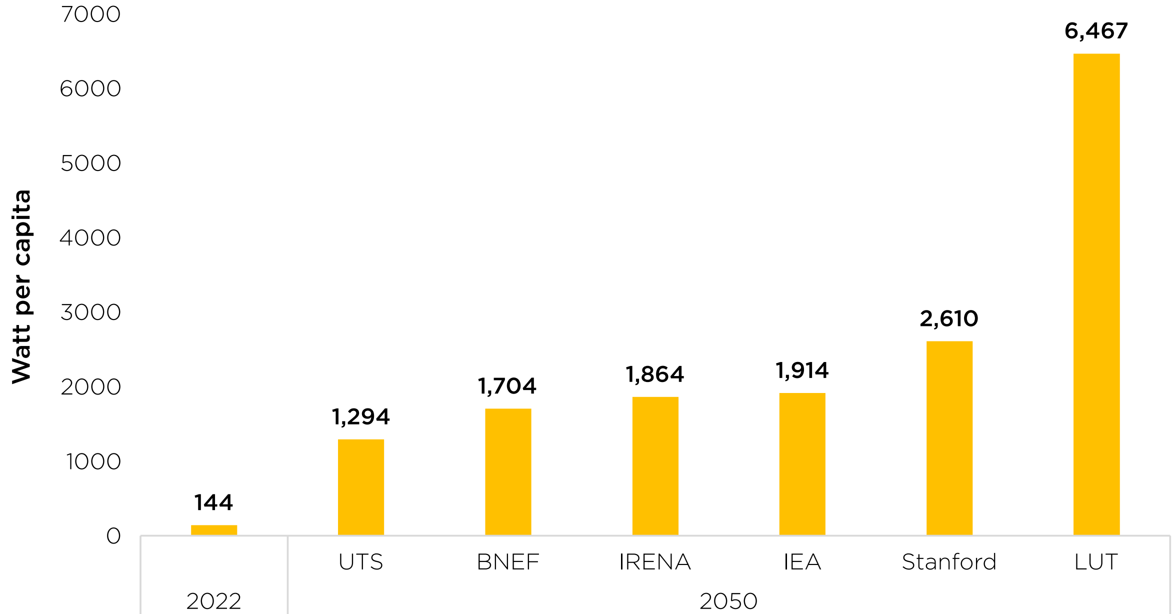


Figure 35: Solar PV watt per capita scenarios in 2050

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

Five out of the six long-term scenarios examined – the UTS, IRENA[9], BNEF, Stanford, and the LUT scenarios – provide regional distributions of global PV capacity deployment in 2050 (see Fig. 36). Even though, the total PV installations differ significantly across the three scenarios for the UTS, IRENA and BNEF, 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 these three scenarios, decreasing from 56% in 2022 to 46-49%. In the Stanford and LUT scenario, the APAC share grows marginally to 59%.

9 Due to the fact that the WETO 2023 does not disclose any data on future regional developments of solar PV, last year's report WETO 2022 had to be used for the regional analysis of deployment levels by 2050.

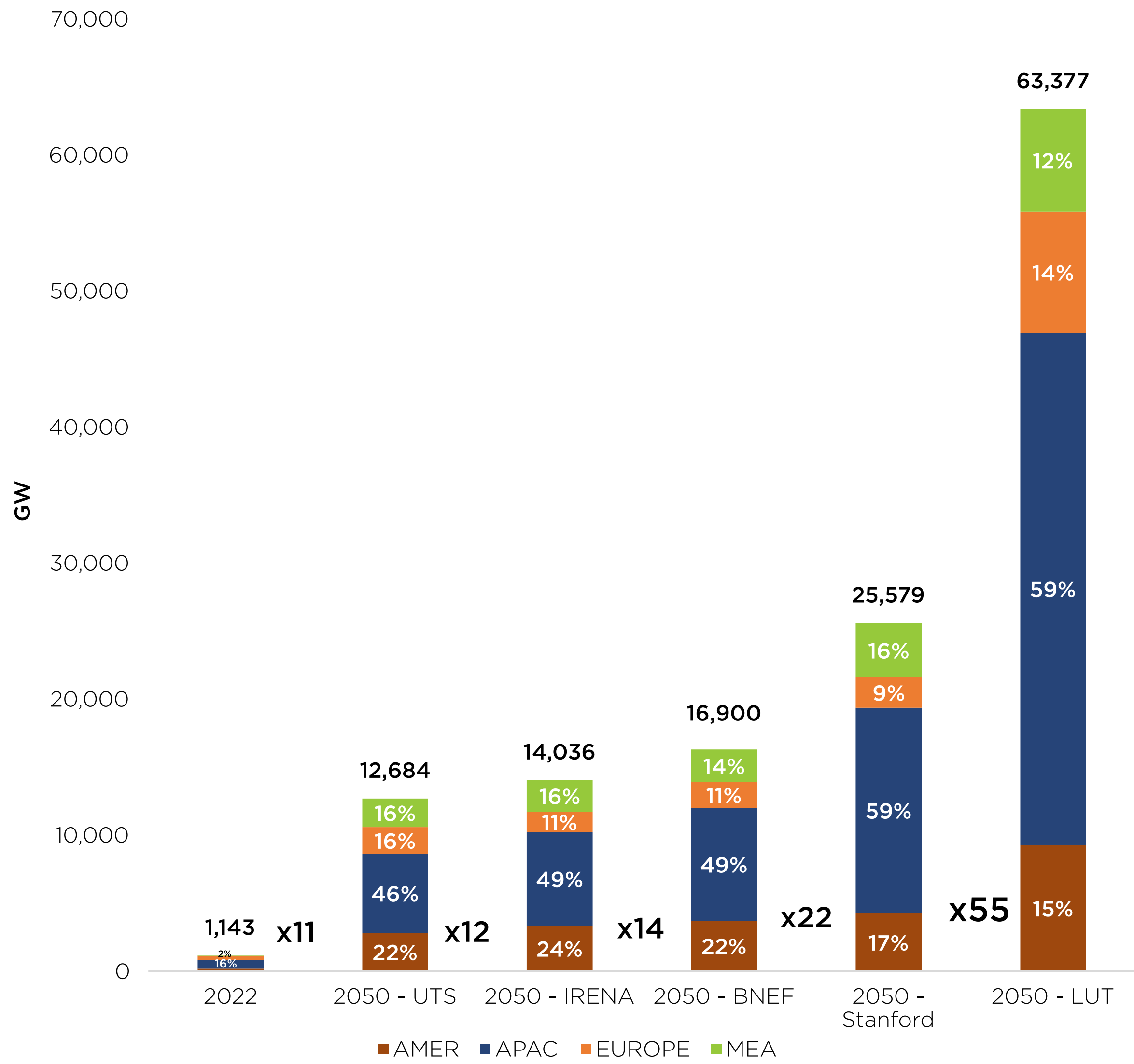


Figure 36: Regional distribution of total installed PV capacity in 2050

Source: UTS, IRENA, BNEF, Stanford, LUT

Many of the long-term studies integrated into the analysis also forecast capacity deployment figures for CSP in their scenarios. An illustration is provided in Figure 37.

By 2050, CSP is expected to augment from the 6.6 GW installed in 2022, to between 426 (IEA) and 1,990 GW (UTS), with IRENA and Stanford scenarios anticipating 864 and 1,151 GW respectively.

This corresponds to an increase in operating CSP capacity in a range between 65 and 302 times from 2022 levels. As previously discussed, the study from the UTS relies heavily on CSP, which downscales the needed expansion of solar PV. This selection of CSP over PV is grounded on the study's preference for technological diversification, differing cost assumptions, and high expectations of the cost reductions of the technology.

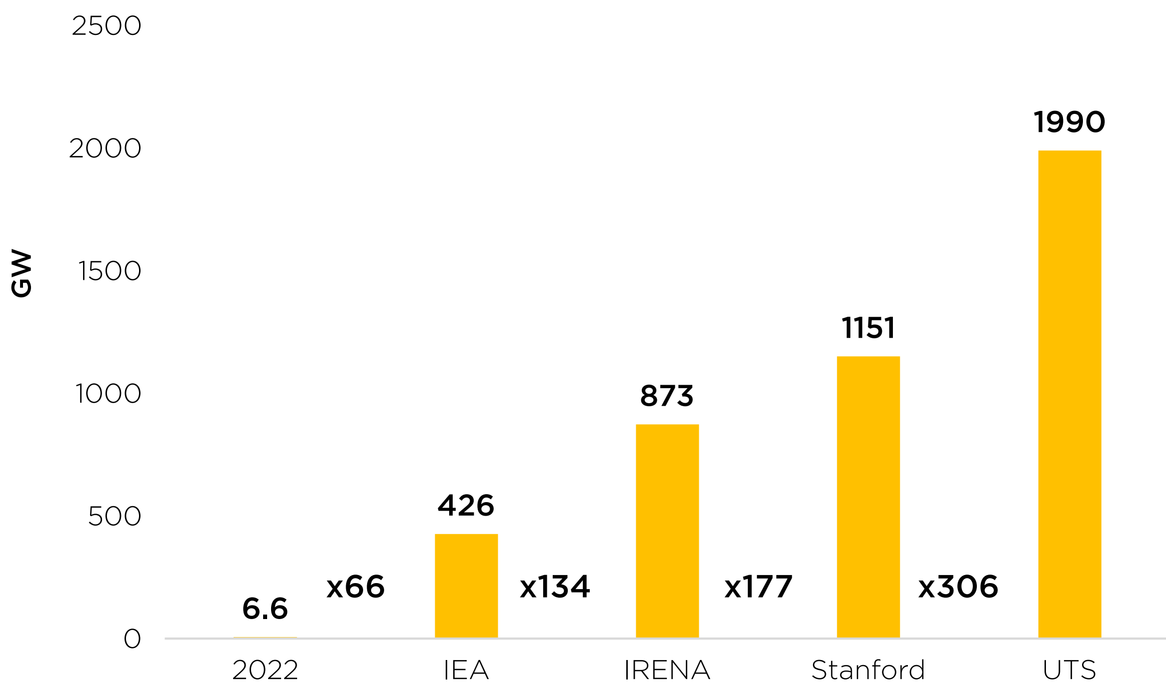


Figure 37: Total CSP installed capacity by 2050
Source: IEA, IRENA, Stanford, UTS

Challenges and drivers to solar market developments

While solar deployment has followed an unprecedented growth trajectory, the development of the technology is not free of any difficulties or obstacles

This chapter elaborates on the main challenges that can emerge and hinder the roll out of solar PV, and renewables more generally. Furthermore, this chapter supplies an assessment of the major supporting plans that have been recently adopted in United States, India, and Europe to boost the development of solar technology. The objectives of these schemes can be divided into two main categories: Firstly, the Production Linked Incentive scheme (India) is narrowly concentrated on the ramping up of the domestic supply of solar technology. Secondly, the Inflation Reduction Act (US) and the European Green Deal aim at, not only reshoring local manufacturing power of solar PV, but also the further acceleration of solar deployment. Therefore, the overarching analysis of the impacts is conducted in that fashion.

5.1. Key Barriers

5.1.1. Social acceptance

Due to the societal nature of the incipient energy transformation, the acceptance of change is a fundamental component of the success of such metamorphosis. A wide array of social, economic and environmental aspects of the solar revolution are under increasing scrutiny, and maintaining a positive social perception remains fundamental to the deployment of solar.

This covers a large set of factors starting from the very capacity of solar technologies to substitute fossil fuels and nuclear plants to meet future energy demands. But topics also cover the financial cost of solar, the opposition to utility-scale PV on the grounds of excessive land consumption, the existence of a synergic relationship between solar parks and natural ecosystems, the electricity production at night, the ability of solar to abate CO_2 emissions, the availability of raw materials to secure solar technology supply, and many more.

All these factors may hinder and slow down the deployment of a multi-terawatt global solar fleet, and it majorly boils down to the concept of social acceptance by local communities. In particular, the global energy transition heightens the competition for land and its intended use. An especially pressing issue in countries with a high population density. The conundrum of NIMBYism (Not In My Backyard opposition) is present across any large-scale solar project, and within the energy sector, but is usually more associated with other energy generation technologies. At the same time, as solar is set to emerge as the primary source of electricity in many countries across the globe, societal acceptance towards solar technology must remain high.

Even today, there are cases of local communities disputing solar projects in their vicinities, despite fundamentally endorsing the expansion of renewable energy solutions. However, with solar being an energy technology that can be decentralised, a substantial part of the generation can take place on rooftops, car parks, traffic routes, public and commercial buildings, and which strongly alleviates the overall solar PV demand for land. Therefore, thanks to its versatility, solar is the technology with the highest acceptance rate in opinion surveys.

Additionally, the possibility of integrating solar into existing infrastructure by utilising it as the shell of buildings (the so-called building integrated photovoltaics, BIPV) further minimizes its visual impact. Options range from solar tiles to roofs, windows, facades, and balconies. Nevertheless, these solutions still necessitate the proactive participation of households and building owners. Preserving a high societal acceptance by effectively communicating the benefits of solar PV is an imperative task in the solar revolution.

While the deployment of rooftop solar is not contingent on a strong social acceptance, the construction of ground-mounted solar projects can face sizable opposition from local communities. It includes concerns over distributional justice (a fair sharing of costs and benefits) and trust among local stakeholders. Directly addressing these concerns and transferring the positive impacts of solar to local communities is critical to secure a just and equitable solar transformation.

Nevertheless, the strongest opposition is commonly related to space utilisation by ground-mounted solar projects, even though research proves that large-scale solar PV can be deployed without any significant conflicts with agriculture or nature conservation and that large solar parks have lower land use impacts than other energy generation technologies[10]. When comparing land transformation and occupation requirements within the complete project life-cycle – material sourcing, manufacturing, transport, utilisation, and end-of-life management – solar technology requires the least amount of land among renewable energy options. In addition, large-scale PV in areas of high solar irradiance also presents lower land requirements when weighed against some traditional energy sources such as coal, if impacts of surface mining such as mountain-top-removal practices are considered.

In terms of preoccupations with biodiversity and ecosystem conservation, implementing best industry practices can turn ground-mounted solar parks into sanctuaries for fauna and flora to thrive. The literature reveals that the solar plant's shading effect can create positive impacts on microclimates, resulting in

10 Fthenakis, V., KIM, H.C., (2009), Land use and electricity generation: A life-cycle analysis, Renewable and Sustainable Energy Reviews., 13 (6–7), pp. 1465-1474.

greater vegetation growth and higher species diversity[11]. Involving environmental experts at an early stage allows developers to factor in all environmental aspects of an installation and enables the ability to create on-site symbiotic relations between solar PV and wild species of plants and animals. Against this background, an appropriate choice of land for the solar park by project developers can be supported by government actions to identify and allocate the most suitable land types for such projects.

It is therefore paramount to rightly design and build large-scale solar plants to minimize competition for land and enable additional value creation on top of green electricity generation. For instance, integrated

11 Armstrong A., and al (2016), Solar park microclimate and vegetation management effects on grassland carbon cycling, Environmental Research Letters, Volume 11, Number 7, DOI 10.1088/1748-9326/11/7/074016.

technological applications such as Agri-PV and Floating-PV present a compelling response to this predicament. Both solutions make intelligent use of space and can diversify income streams for farmers and landowners. PV panels offer a buffering effect to agricultural production facing extreme climatic events and can create optimal conditions for enhanced productivity. Numerous studies have shown that shading by PV panels decreases drought stress on plants, increases food and biomass production, reduces heat stress and protects plants against severe weather events. A wide set of benefits arises in artificial water bodies too: less water evaporation, increased efficiency of solar panels due to the cooling effect of water, synergies with hydro-power facilities, creation of new habitats under the Floating-PV platforms, reduced albedo effects in water bodies, and more.

5.1.2. Fossil fuel subsidies

Prices for fossil fuels were strikingly high and volatile in 2022 as energy markets wrestled against the enormous hit caused by the Russian invasion of Ukraine, and the remnants of the COVID-19 pandemic. This tension in energy markets was even more prominent in Europe and other regions as Russia sharply reduced natural gas deliveries, causing energy prices to soar. In countries where the impact was profound, emergency aid packages were rolled out to shield consumers from astronomical prices, at the damaging expense of artificially maintaining fossil fuel market competitiveness against low-carbon and cheap alternatives. The IEA calculates that more than $ 500 billion were spent to lower energy bills in 2022, mainly in advanced economies, with around $ 350 billion of this in Europe[12].

Therefore, and even though the renewable uptake in 2022 was immense, the provision of explicit or implicit subsidies to hydrocarbons wind down the pace of the energy transition as the economic incentive to replace fossil technologies with renewables diminishes. It also comes at a fiscal burden for many countries: firstly, as a financial cost, considering that fossil fuel industries benefit from taxpayers' money; and secondly, as a societal cost, resulting from the burning of fossil fuels and the resulting release of greenhouse gas emissions which impose negative externalities (e.g. air pollution leading to higher public health spending) on society and the environment. Fossil fuel emissions are generally not priced and consequently not internalised by polluters, which enjoy as a result an indirect subsidy in the market. This further unrealistically maintains hydrocarbon prices low. It is also important to highlight that low-carbon and cost-efficient technologies have a deflationary impact on energy prices in the long term, while subsidies to fossil fuels are only further driving prices up.

In other words, fossil fuel subsidies distort the efficient allocation of resources, which could be otherwise diverted to sustainable solutions that increase social and environmental welfare. The IEA estimates that explicit worldwide subsidies (undercharging for supply costs) to fossil fuel companies swelled to $ 1.4 trillion in 2022, by far the largest annual value ever witnessed. In comparison, fossil fuel subsidies in 2020 amounted to slightly more than $ 200 billion and hadbeen on a three-year decline since 2018 (nearly $ 600 billion that year). According to the agency, this explicit subsidy amount is expected to fall over the years, if fuel prices recede in international markets, and temporary price support measures are eliminated. In terms of implicit subsidies (undercharging for environmental costs and forgone consumption taxes), the International Monetary Fund estimates a total of $ 5.7 trillion in 2022[13]. Therefore, global fossil fuel subsidies amounted to $ 7 trillion in 2022,

12 IEA (2023), Fossil Fuels Consumption Subsidies 2022, IEA, Paris https://www.iea.org/reports/fossil-fuels-consumption-subsidies-2022, License: CC BY 4.0

13 Black, S., and al. (2023), IMF Fossil Fuel Subsidies Data: 2023 update, Working Paper No. 2023/169.

which is equivalent to approximately 7.1% of world GDP.

With renewable electricity being much cheaper than fossil fuel power in many countries across the world today, the economic disadvantage of fossil fuel subsidies becomes evident. Consequently, this represents an opportunity to redirect investments and public spending to accelerate the advancement of renewables.

5.1.3. Labour availability

A carbon-neutral economy entails the creation of an entirely new set of jobs in renewables, energy efficiency, the circular economy and related sectors as fossil fuels are progressively phased out – rendering a net increase in the number of energy jobs overall. As the energy metamorphosis unfolds, the international consensus is that a just energy transition is imperative – meaning that, the decarbonisation of the global economy has to be executed in a fair and inclusive way, providing decent work, and leaving no one behind.

The number of people employed in the renewable energy sector has steadily increased over the past decade. IRENA estimates reveal that renewable employment has been augmented by 88%, from 7.3 million in 2012 to 13.7 million in 2022[14]. To contextualise this data, it is worth mentioning that according to the IEA, approximately 65 million people were employed in the energy industry worldwide in 2021.

IRENA calculates that around 4.3 million workers were employed in the solar PV sector in 2021, up from about 4 million in 2020. This large number of solar workers is not a surprise, given that solar power is the fastest-growing energy industry and the most labour-intensive among all low-carbon and renewable energy technologies. As certain regions of the world struggle to renovate their national industries and maintain a stable domestic job creation rate, solar PV offers an excellent economic opportunity for local job creation. Conveniently, the majority of solar jobs are created in the installation phase, which occurs at the local level. But high-quality jobs are created throughout the entire solar life cycle in manufacturing, operations and maintenance, and decommissioning and recycling.

However, the immense job creation process that the sector is poised to experience is a double-edged sword that can create a major bottleneck for the development of solar. Solar PV is growing at an exponential rate, and such growth has to be accompanied by a proportional increase in the solar workforce. Already today, at the initial deployment growth phase of the sector, the shortage of installers worldwide represents an obstacle to the acceleration of solar adoption. Even where solar administrative barriers are lifted and solar panels are readily available, substantial delays of up to a year are reported to install solar rooftop PV systems. Waiting times can be even longer if combined with battery storage or heat pumps.

Considering the speed at which solar employment has to be expanded, it is therefore paramount to promote technical careers and education in solar jobs at all scales. In parallel, it will be important to monitor the quality of the jobs offered, and the ability to attract and retain solar workers, a profession that is tremendously underrepresented nowadays.

5.1.4. Administration and permitting

In the past years, administrative hurdles have become a major bottleneck that further stands in the way of a fast and favourable development of renewable energy sources. The most pressing barriers related to the administrative process for renewable projects

14 IRENA and ILO (2023), Renewable energy and jobs: Annual review 2023, International Renewable Energy Agency, Abu Dhabi and International Labour Organization, Geneva.

are bureaucratic burdens, non-transparent procedures, a lack of legal coherence as well as incomplete and imprecise frameworks and guidelines that result in diverging

interpretations of existing legislation by the competent authorities. In some countries, the lack of appropriate spatial planning is a particularly challenging matter. This can arise because spatial plans do not earmark land for renewable projects and therefore developers often have to achieve a modification in existing schemes. This can take a substantial amount of time and delay the final commission of the project.

Another ubiquitous roadblock is the shortage of experienced staff. This obstacle either emerges from a shortage of public clerks to process applications and/or the pertinent staff lack the required experience or technical skills to execute these tasks. A further issue is that most countries have not digitalised permitting, and therefore applications still depend on excessive paperwork.

Conflicting environmental and wild species protection regulations and land use planning tensions also pose a prominent barrier to the deployment of renewables. However, in this sense, speeding up administrative and permitting should not come at the expense of preserving species and natural habitats in the context of an unprecedented biodiversity global emergency. Therefore, and as mentioned before, dual-use solutions must be prioritised as a way to preserve ecosystems while producing green electricity.

An illustrative example of too-long permitting procedures is the deployment of ground-mounted solar PV installations in the EU which can take up to 5 years, which is incompatible with the deployment pace required to ensure a graceful energy transition. The European Commission revealed in 2022 that administrative and grid issues constitute about 46% of all identified hurdles to renewable energy projects.

To address administrative and permitting obstacles, it is fundamental to set clear guidelines to efficiently streamline bureaucratic procedures. These policies should focus on three major areas: simplifying permitting procedures and/or setting crystal clear permitting timelines; targeting preferential areas for renewable energy projects to fast-track permitting; and removing certain permitting requirements for small-scale renewable projects or augmenting the minimum capacity requirements for environmental impact assessments. These amendments aim at reducing permitting lead times, increasing project bankability, and ultimately boosting the rollout of renewable energy technology globally.

5.1.5. Curtailment

International power markets in the summer of 2023 have been at times afflicted by wholesale prices plummeting to negative levels. According to the IEA, the number of hours with power prices dropping below zero doubled in countries such as Germany and the Netherlands during the first half of 2023, relative to the same period in 2022. Other examples are California, which saw negative prices about 1% of the time and South Australia where wholesale electricity market prices were below zero almost 20% of the time in 2022.

This negative price phenomenon occurs when the grid experiences a 'congestion', which refers to a situation in which the grid cannot integrate the electricity produced by power plants. As a result, prices in wholesale power markets steeply decrease below zero and solar PV power plants have to temporarily shut down due to unexpectedly low or inexistant profit margins. Due to this 'economic curtailment', solar energy is wasted, especially during summer months. In addition, unaddressed volatility of energy prices and recurrent negative prices endanger investments in new solar PV assets.

To resolve this predicament, a massive push for flexibility measures is needed. In other words, heavily increasing the capacity to cover with dispatchable sources the potential intermittency of renewable energy sources. It comes in the form of more flexible operations, more flexible generation, stronger grids, more energy storage, demand response, hydrogen for renewable power, heat pumps, and faster uptake of electromobility.

Concerning power grids, traditional electricity networks were constructed to transport, distribute and deliver electricity from centralised sources to end-consumers in a rather linear and inflexible fashion. The high penetration of variable and decentralised energy sources comes together with a set of technical challenges related to grids and the management of distributed power stations. With the incipient increase in power demand stemming from the electrification of the heating and transport sectors, grid capacity needs to be sizably reinforced, expanded both nationally and internationally, modernised and digitalised.

Yet, several countries are already facing grid congestion problems, which cause delays in the development, commission, and entry into operation of solar projects. To avoid a scenario where grid constraints become the norm, governments and national transmission systems need to sizably increase the level of investments into grids and flexibility solutions such as energy storage to avoid existing limitations to exacerbate. The IEA's World Energy Investment Report 2023 highlighted that global investment on power grids has not yet significantly increased across the past years, relative to investments in renewable energy adoption. An insufficient increase of 8% was recorded in 2022, relative to 2021, but initial signs in 2023 reveal a flattening in spending efforts. The distribution of investments reveals that most of the spending is conducted by advanced economies and China, while investments into grids is rapidly falling in emerging and developing countries.

Massively promoting flexible resources, both on the demand side and the generation side is also fundamental. Hybrid solar projects coupling solar with energy storage or coupling solar and another complementary renewable energy source, such as wind offer an effective, flexible, and cost-efficient solution. When the sun does not shine, the wind blows, and when there is neither, storage serves as a flexible dispatchable source of power. Other grid-connected devices such as heat pumps, electric vehicles, home appliances and electrolysers can also enhance the flexibility of the electricity network. But also flexibility is needed on the demand side, to shift energy consumption to off-peak hours by developing appropriate demand action plans including simple, non-market, price signals, such as the Time of Use grid tariffs or self-consumption schemes.

Lastly, boosting the diffusion of smart building technology. Energy renovation rates must be fast-tracked to digitalise buildings and make them increasingly responsive to grid price signals. Simultaneously, buildings should be equipped with battery storage or smart heat pumps to allow the increase of flexibility potential, and consumers should be allowed to limit the import or export of electricity at the grid connection point.

5.1.6. Energy storage solutions

The continued rapid expansion of variable renewable energy generation can only reach its maximum potential through the widespread adoption of additional energy storage technologies. As the share of variable renewable energy sources in the electricity grid grows, so does the demand for flexibility and reliability. Energy storage will have to play the pivotal role in delivering the flexibility and stability to the grid, serving as a low-emission alternative to traditional fossil-fuel power plants that typically supply electricity during peak demand periods or in periods with little or no solar and wind output.

While the capacity of utility-scale and small-scale battery storage has been increasing over the past few years, it still falls short of the scale and pace required to support a future energy system relying on variable renewable energy sources. To accommodate the substantial influx of renewables into the grid in the years to come, substantial investments in energy storage, including thermal energy storage, are imperative. In addition to short-term storage solutions like batteries, there is a need for long-term energy storage options such as hydrogen to provide weekly or monthly storage capacity.

Realising the full potential of energy storage technologies is therefore a mandatory condition to enable the seamless integration of renewables by managing the variability of renewable generation output and enhancing grid capacity. Energy storage mitigates price fluctuations during peak periods, stabilizes electricity prices, and optimises energy use by shifting surplus energy from low-price periods to high-price periods. At the system level, energy storage is a valuable asset for network operators in managing access to grids and operating the energy system efficiently.

Despite its rapid cost decrease and technology improvements, several barriers hinder the rapid deployment of energy storage solutions.

- **Policy and regulatory frameworks:** Many countries are still missing appropriate policy frameworks to for discriminatory-free grid conntections. Policy and regulatory barriers often make it still difficult to deploy battery storage systems, such as unclear regulatory frameworks, high fees and taxes. Missing appropriate guidelines for ancillary service markets hinder operation in this business segment where renewable based energy storage can play a crucial role in decarbonizing the grid.
- **Public awareness:** A major obstacle is unawareness among policy makers, missing regulatory frameworks, and high fees and taxes, all of which limits deployment and economic operation of battery storage.
- **Grid integration challenges:** Simplifying the integration of energy storage solutions into the power system is crucial. The processes of connecting storage to the electric grid is often complex and untransparent, resulting in significant project delays. Grid operators and national regulatory agencies must take immediate action in streamlining the connection of queued projects.
- **Cost:** Economic considerations also pose limitations on the deployment of storage solutions. Battery storage systems are still relatively expensive, despite significant cost reductions in recent years that are continuing. This can make it difficult for developers to finance large-scale projects, especially in today's economic environment of high interest rates across the globe. Additionally, there is a need for upgrades to energy and power systems, further increasing the overall cost of energy storage. This economic challenge extends to long-term solutions such as renewable hydrogen, which is not yet cost-competitive when compared to fossil fuels.

5.1.7. Solar PV manufacturing concentration

A major geographical readjustment has occurred in solar PV manufacturing capacity over the last decade, as China further strengthened its leading position as a global industrial powerhouse for the production of wafers, cells, and modules. For polysilicon, the country's production share in global markets nearly tripled between 2010 and 2021[15].

Today, the IEA's State of Clean Technology Manufacturing states that three countries absorbed nearly 90% of installed capacity for manufacturing solar PV modules, with China accounting for an average of 80% across all production segments[16]. Some factories in China are large enough to supply half of the capacity additions of solar PV modules in the European Union for 2022, which totalled nearly 41 GW. The next two largest manufacturing countries are Vietnam

15 IEA (2022), Solar PV Global Supply Chains, IEA, Paris https://www.iea.org/reports/solar-pv-global-supply-chains, License: CC BY 4.0

16 IEA (2023), The State of Clean Technology Manufacturing, IEA, Paris https://www.iea.org/reports/the-state-of-clean-technology-manufacturing, License: CC BY 4.0

and India[17], accounting respectively for 5% and 3%. The largest manufacturing plants in these countries are generally far smaller than those in China, at around 7-8 GW of annual production capacity. Moreover, if all announced plans materialise, concentration among the top three manufacturing countries would remain very similar (90%), with some sizable changes in the production ranking. The second largest manufacturing country, Vietnam, would cede its place to India, today's third largest, as well as to the United States, which would move third. The share of China would remain almost entirely identical at 80%.

On the one hand, this concentrated configuration of solar PV manufacturing reflects that the technology has reached a mature stage of development, as solar PV is nowadays massively installed all around the world and supply of solar PV modules significantly exceed current demand. This provides huge investment certainty and stability, as solar PV already accounts for nearly 40% of global electricity capacity additions in 2022. On the other hand, manufacturing concentration in Asia raises security-of-supply concerns which could potentially decelerate the pace of solar PV expansion globally. Current low-diversification levels make the supply chain highly vulnerable to single incidents - geopolitical tensions, natural disasters, wars, a pandemic, technical failures or individual company decisions. Historically speaking, all these risks have unfolded, leading to major disruptions and drastic price increases in the supply of solar PV technology, that could potentially jeopardise the entire global energy transformation.

Consequently, governments in the United States, Europe and India have begun to prioritise the diversification of solar PV supply chains by the adoption of industrial policies such as India´s Production Linked

17 For further information on PV manufacturing in India see : Shiradkar, N., and al. (2022), Recent development in solar manufacturing in India, Solar Compass, Volume 1, https://doi.org/10.1016/j.solcom.2022.100009

Incentive (PLI) scheme and the US Inflation Reduction Act (IRA) to procure direct financial incentives for domestic manufacturers to level the competitive playing field with their Chinese counterparts. The response has been immediate. Over 120% more new solar PV manufacturing projects have been announced from November 2022 to May 2023, with capacities over 20 GW in each region. Therefore, the reshoring of domestic solar industries has to be guided by effective financial support frameworks that assist companies to expand their operations to the gigawatt-scale to achieve cost reductions, economies of scale and maintain a robust financial health during the first years of operations.

5.2. Overview of major supporting policies

5.2.1. The Inflation Reduction Act – United States of America

On August 16, 2022, President Joe Biden signed the IRA into law, marshalling the largest burst in spending in U.S. history to combat global warming - about $400 billion to drastically slash the country's emissions and bring the climate goals within reach. The bill aims to abate greenhouse gas emissions by 40% relative to 2005 levels by the end of 2030.

But it is not just about climate protection: The IRA also addresses a large number of topics, including lowering health care costs, funding the Internal Revenue Service, and improving taxpayer compliance and it strives to raise nearly $800 billion in governmental revenues.

The act aspires to catalyse investments in

domestic manufacturing capacity, incentivise the local supply of critical components or from free-trade partners, and head start R&D and marketing of avant-garde technologies such as carbon capture and storage, long term energy storage or renewable hydrogen. It also channels funds to environmental justice actions and requires recipients of many funding streams to evidence equity impacts.

Therefore, the package marks a critical shift in the U.S. economy by concentrating on rebuilding the national manufacturing base and reversing the massive offshoring of industry jobs that the country experienced in recent decades. To do so, the bill utilises two main levers for the advancement of renewable technology: major new incentives for the private industry to produce far more clean energy, and targeted incentives for households to transform their energy use and consumption.

The lion's share of the investment program (around $260 billion) is absorbed by the renewable energy sector. New and extended credits are provided for private firms and publicly owned utilities producing clean energy and manufacturing essential components of renewable projects domestically. Approximately 22% of the funding ($80 billion) is channelled for new rebates on electric vehicle purchases, and household adoption of clean and efficient technology. $1.5 billion will be utilised to fund the Methane Emissions Reduction Program, which rewards oil and gas companies that cut their methane emissions and penalises those who do not. A Clean Energy and Sustainability Accelerator, commonly branded as a green bank, provides $27 billion of financing to eligible financial institutions to make investments directly into projects that decrease carbon emissions, support communities adversely affected by climate change, and provide technical assistance for the opening of new green banks across the U.S. The remaining is directed towards healthcare, reinforcing the IRS budget, and various subsidies aimed at decarbonising certain economic sectors such as agriculture or steel production with high emissions.

5.2.1.1. Solar Manufacturing Incentives

The IRA establishes two types of credit for solar manufacturers. Firstly, a 30% investment tax credit (ITC) for eligible investment costs in facilities and equipment, and secondly, a production tax credit (PCT) for certain components based on the volume of goods manufactured. Solar manufacturers can only utilise one of the two tax credit schemes.

A total of $10 billion are to be allocated for the manufacturing ITC in additional credits to qualifying solar manufacturing projects starting in 2023. Up to $6 billion are set aside for projects located in census tracts where a coal mine closed after 1999 or a coal-fired power plant was decommissioned after 2009. To receive the entirety of the 30% credit, the workers involved in the manufacturing project must meet existing wage and apprenticeship requirements. If not, the tax credit is reduced to 6%.

Interestingly, the choice to utilize the solar investment tax credit or the production tax credit now includes the ability to transfer credits which creates a whole new market. This provides developers with the freedom to sell the complete amount or a part of the credits to external parties. This places developers in a position of control, allowing them to fine-tune projects, attain optimal value, or substantially diminish project-related risks.

Additionally, the Ossoff Manufacturing Credits specifies different bonus rates for the domestic production of solar panels, inverters, and racking components, which further increases the financial attractiveness for solar manufacturers. Nonetheless, the real benefit of the new tax incentives scheme is the timeframe, which extends the bill's credits and incentives for 10 years, providing certainty and making manufacturing investment in the U.S. viable.

5.2.1.2. Solar installations and storage

Solar plays a central role in the IRA's efforts to decarbonise and onshore U.S. energy needs. The investment program has been heralded as a new dawn for U.S. solar following arduous years for the industry that has witnessed import restrictions on Chinese products, supply chain disruptions and geopolitical events causing soaring module prices and increasing pressure on project costs. This resulted in project delays and cancellations, and a major slowdown in the rollout of solar as the PV market contracted by 15% in 2022[18].

For the residential segment, the personal ITC of solar energy property is extended and raised to 30% of capital costs until 2033 (pre-IRA stood at 26% and was to be eliminated in 2024), falling to 26% in 2033, and 22% in 2024. Residential energy storage installations were previously ineligible for tax credits unless they were connected directly to power generated from solar. The IRA removes these requirements and enables stand-alone batteries of at least 3 kWh of capacity to also qualify for the same 30% tax credit.

For utility-scale, commercial, industrial, non-profit, government, etc., the ITC is protracted and improved to 30% for projects that have started or start construction before the end of 2024. Stand-alone storage installations also benefit from the tax credit. Solar also becomes eligible for the production tax credit (PTC) which currently stands at $0.025/kWh for 2022, and increases linked to inflation. Stand-alone storage can only benefit from the ITC. After 2024, the credit morphs into a ''technology neutral'' structure.

Under the scheme, solar projects are enabled to choose the ITC or PTC and both credits come with potential bonuses for meeting certain domestic content and location requirements. Solar power projects can increase their tax credit by an additional 10% by purchasing nationally produced equipment. Steel and iron must be U.S. manufactured, and for solar components, the goods must be at least 40% U.S. produced (this rate will be increased in the future).

Additionally, projects that are located in communities that were dependent on fossil fuel production over the last generation (so-called 'energy communities' or 'brownfields'), or projects selling electricity via community solar to low-income households can earn an additional 10% tax credit. These bonuses are not mutually exclusive, which means that if we add 30% tax credit base, 10% for domestic content, 10% for being located in a brownfield, and 10% for supplying power via community solar to low-income families – the tax credit potentially reaches 60%

Interconnection costs are also covered under the ITC for projects smaller than 5 MW of installed capacity. This measure is particularly advantageous for a U.S. solar market heavily burdened with project soft costs, which can exceed 65% of the total expenses according to the US Department of Energy.

5.2.1.3. Impacts on the Solar Industry

In the short term, by the time of publication of this report – approximately one year after the IRA was adopted – the impacts on solar PV deployment have been somewhat limited so far. The U.S. solar market experienced a turbulent year in 2022 but kept its spot as the second-largest market in the world. The country installed 21.9 GW, a 6% annual decrease in a year (23.4 GW installed in 2021) prompted by the anticircumvention investigations, the Uyghur Forced Labor Protection Act (UFLPA), and the passing of the historical IRA[19].

In the first quarter of 2023, the U.S. solar industry installed 6.1 GW of capacity, a 47% increase from Q1 2022[20]. It was the best first

18 IEA (2023): Renewable Energy Market Update

19 SolarPower Europe (2023): Global Market Outlook for Solar Power 2023-2027.

20 Solar Energy Industry Association (2023), U.S Solar Market Registers Best First Quarter in Industry History as Supply Chains Stabilize and Inflation Reduction Act Takes Hold.

quarter in the industry's history, as supply chain hurdles diminished and delayed utility-scale solar plants came online. However, solar installations in Q1 2023 decreased by 19% relative to Q4 2022. In Q2 2023, the U.S. installed 2.7 GW of capacity, accounting for more than half of all clean power additions.

As expected, the long-term tax incentives in place will only make a sizable impact on PV deployment after 2025[21]. The IEA states that projects to be grid-connected in the coming two years have already benefitted from pre-IRA policies, the lifting of existing trade barriers, and the removal of supply chain challenges. Therefore, the short-term impacts of the IRA on solar deployment are difficult to account for. Nevertheless, the IRA establishes a firm regulatory framework that incentivises investment for solar projects up to 2032.

Concerning solar manufacturing, the law has spurred investment in clean technology. According to the Solar Energy Industries Association[22], over $100 billion of private capital investments have been announced by U.S. solar and storage companies. In contrast, from 2017 to 2021, an equivalent amount was invested in domestic clean manufacturing.

Therefore, solar manufacturing is now surging in the U.S. as 51 solar factories have been announced or expanded since the IRA was adopted one year ago. As a result, 155 GW of new production capacity has been announced across the solar supply chain. These announcements include 85 GW of solar module capacity, 43 GW of solar cells, 20 GW of silicon ingots and wafers, and 7 GW of inverters. Additionally, 65 GWh of power storage production capacity has been announced across 14 new or expanded factories. According to SEIA, the U.S. solar industry is aiming at a goal of having 50 GW of domestic solar manufacturing capacity across all key supply chain segments by 2030. Moreover, over the next decade, industry employment is expected to nearly double from 263,000 in August 2023 to 478,000 by 2033.

As of current production capacity, however, the U.S. has no domestic solar ingot, wafer, or cell manufacturing capacity and only modest capacity to produce solar modules. According to data from August 2023 from the US Department of Energy (DOE)[23], the country only produces 244 kilotons of silicon or polysilicon per year, 20 MW of wafers, 1.7 GW of c-Si cells, and 5.6 GW of module manufacturing capacity. The DOE does not report any production capacity for ingots. For inverters, it is estimated that the U.S. produces 8.4 GW on an annual basis.

5.2.2. The Production Linked Incentive – India

Despite India's successful growth story over the past few years, as the country grew its economy in double digits every year, India's manufacturing sector has suffered critical damages due to two consecutive hits. First, a faulty implementation of the Goods and Services Tax reform and, second, the COVID-19 pandemic. As a result, demand receded in the country, which destroyed millions of jobs in the country, and consequently, purchasing power declined among consumers. Additionally, India's massive trade deficit and over-dependence on China further depressed the economic panorama. All these factors induced a shift in the economic and industrial policy-making of the country, as a rebuilding of the production capacity had the potential to tackle economic stagnation.

The Production Linked Incentive (PLI) scheme was launched in November 2020 as the latest addition to the list of reforms

21 IEA (2023), Renewable Energy Market Update - June 2023, IEA, Paris https://www.iea.org/reports/renewable-energy-market-update-june-2023, License: CC BY 4.0

22 Solar Energy Industry Association (2023), Solar and Storage Companies Add Over $100 Billion to U.S. Economy as a Result of the Inflation Reduction Act

23 Department of Energy, Solar Manufacturing Map: https://www.energy.gov/eere/solar/solar-manufacturing-map.

introduced under the 'AatmaNirbhar Bharat Abhiyan' (Self-Reliant India) initiative. These incentives are specifically devised to scale up local manufacturing in strategic sectors, curtail import volumes, strengthen the cost competitiveness of domestically manufactured goods, attain increasing economies of scale, and increment the exporting capacity of the country. The scheme also concentrates on attracting foreign companies to set up factories in India, while simultaneously stimulating local producers to set up or expand existing facilities. This generates a boost in job creation and a reduction of import dependencies.

At its inception, the initial financial outlay of the PLI scheme totalled around 2 trillion Rupees ($27 billion) investment to expand India's manufacturing power over a 5-6 year period. The first industry to receive support from the PLI scheme was the large-scale electronics manufacturing sector, as the Indian government attempted to reduce reliance on Chinese imports. By the end of the year, 10 more sectors were announced as recipients of the incentives scheme. Currently, 14 sectors are included under the PLI programme. Among these strategic sectors, we find pharmaceuticals, food processing, steel production, telecommunications, textiles or manufacturing of high-efficiency solar PV modules and batteries.

5.2.2.1. Solar Manufacturing Incentives

Addressing the risks posed by heavy reliance on imports of solar PV and to boost domestic solar manufacturing, in 2020 the government designed a focused PLI scheme (High-Efficiency solar PV Modules) supporting the build-up of gigawatt-scale solar PV capacity in India and the seizing of larger shares of the global solar PV value chains.

The national programme on solar PV manufacturing has been phased into two financial tranches: the first one was initially launched as part of the first PLI scheme and injected around $0.6 billion. It intended to generate sufficient vertically integrated factory capacity to produce 10 GW of solar panels every year.

In this first tranche, beneficiaries of the PLI scheme were selected via a bidding process after applicants were shortlisted based on parameters such as proposed manufacturing capacity and module performance, and the level of vertical integration in the value chain. However, preference was mainly given based on the level of manufacturing integration. Companies aiming at setting up production capacities above 1 GW for at least cells and modules, had an edge for obtaining the funds. Shortlisted candidates then registered bids based on the level of PLI funding they necessitated for the next five years after their planned facilities were commissioned. Then, successful applicants are selected, and winners received a maximum incentive linked to 2 GW of annual production capacity or half of the planned output of their facility. Financial injections are then executed based on actual production levels and module sales.

The initial PLI tender received a more than fourfold oversubscription, which prompted the government to announce a second phase which was initiated in September 2022. This second tranche totals $2.37 billion and aims to incentivise the construction of 65 GW of fully and partially integrated solar PV manufacturing capacity in the country. Following a similar selection procedure, solar manufacturers setting up factories will be eligible to apply for the incentives provided that they commit to building production capacities for at least solar cells and modules, and comply with minimum capacity and module performance standards. Under this tranche, eligible applicants can opt to bid to any of three categories of integration: polysilicon-to-module, ingot-wafers-to-module, and cells-modules.

The financial incentives available positively correlate with the level of manufacturing integration. Hence, approximately $1.48

billion are destined for the polysilicon-module category, $0.55 billion for the ingot-wafers-to-module manufacturers, and $0.37 billion available for cells-modules producers. Each manufacturer may register a single bid to establish a solar factory of at least 1 GW of production capacity for each production segment. There are maximum capacities that solar producers can apply for 1 GW for the polysilicon-to-module category and 6 GW each for wafer-to-module and cells-modules categories. However, the maximum capacity that is qualified for a grant under the PLI scheme will be 50% of the capacity built by the bidder.

5.2.2.2. Impacts on the Solar Manufacturing Industry

Growth in terms of deployment of solar PV in India has not so far translated into massive growth of local manufacturing capacity. In 2022, India achieved a remarkable milestone by introducing approximately 14 GW of additional solar capacity, marking it as a record-breaking year for annual capacity expansion. By the close of December 2022, the cumulative solar installations in India reached an impressive 63.5 GW, solidifying the nation's position as the world's fifth-largest in terms of installed solar capacity. Furthermore, India has undertaken a significant revision of its solar target for 2030, now aiming to achieve 300 GW out of a total of 500 GW of renewable energy capacity. As a result of this ambitious adjustment, India is poised to experience an annual surge in solar capacity between 20 to 30 GW starting from 2023 onwards[24].

Nevertheless, according to the IEA[25], India's efforts to increase domestic manufacturing are creating a mismatch between supply and demand. This disparity has resulted in higher prices for PV systems in the short term, which is adversely affecting PV deployment in 2023 and will continue to do so in 2024. Historically, China has supplied 75% of India's solar fleet during the last five years and the PLI scheme for solar manufacturing is intended to minimize or eliminate those imports of PV. The two rounds of the incentives scheme should enable India to decouple its solar growth from imports in the next four to five years.

As of November 2021, India had a cell manufacturing capacity of 4.3GW and a module manufacturing capacity of approximately 18GW[26]. These are, however, just nameplate capacities. Actual production output at any given time is significantly lower as most of Indian solar manufacturing facilities operate at a Capacity Utilisation Factor (CUF) of less than 50%.

By March 2022, there had been more than 60 GW of announcements from domestic producers, but only 12 GW were selected for benefitting from the PLI scheme. In February 2023, the government released government Approved List of Models and Manufacturers (ALMM) which totalled a considerable scale of 22 GW of PV production capacity. However, only less than 5 GW are dedicated to high-capacity modules (over 500 W of nameplate capacity), which creates a large gap between demand from large-scale top-tier manufacturers and the supply of those products. PV developers in India heavily demand these high-efficiency top-tier modules because of their cost efficiency and bankability.

In addition to the existing rift between supply and demand, the introduction of moderate import duties did not create a very attractive playing field for enlarging domestic manufacturing capacity. Early attempts from Chinese producers to establish in India did not materialise either. Other locations in Southeast

24 SolarPower Europe (2023): Global Market Outlook for Solar Power 2023-2027

25 IEA (2023), Renewable Energy Market Update - June 2023, IEA, Paris https://www.iea.org/reports/renewable-energy-market-update-june-2023, License: CC BY 4.0.

26 Analytics & Institute for Energy Economics and Financial Analysis & JMK Research (2022), Photovoltaic Manufacturing Outlook in India : https://ieefa.org/resources/photovoltaic-manufacturing-outlook-india.

Asia (Vietnam, Malaysia, o Thailand) witnessed higher increases in manufacturing capacity as better conditions drew more suppliers outside mainland China.

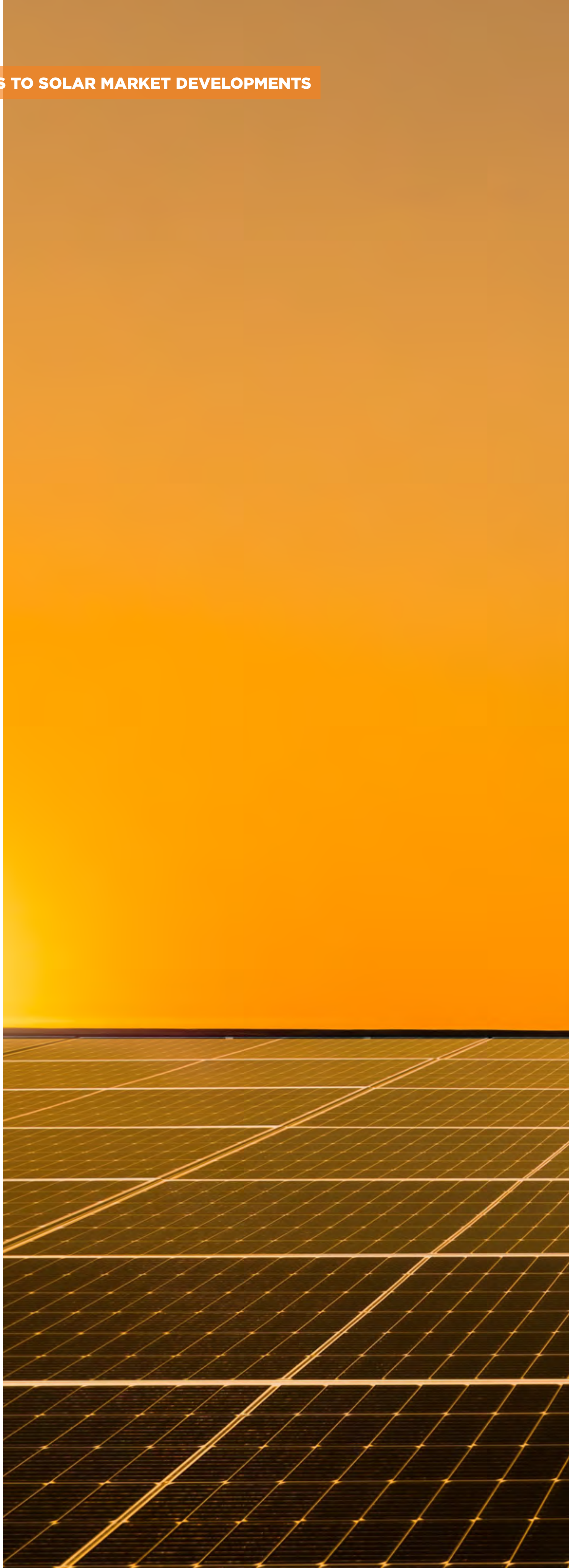
Nevertheless, even if a large share of these announcements are not developed, S&P Global projects India to have the largest global expansion rate for module production in the coming two or three years (more than a 30% annual growth rate)[27]. In the meantime, India's PV industry will still sizably rely on China for sourcing raw materials (for example, wafers) given the lead times required to set up vertically integrated capacity in the country.

5.2.3. The European Green Deal – European Union

In April 2009, the first Renewable Energy Directive (RED) was adopted in the EU, setting up the legal framework for the deployment of renewables across all sectors of the EU economy. Between then and the end of 2018, the total PV capacity of grid-connected solar PV systems in the EU increased more than 10-fold from around 11 GW in 2018 to over 110 GW at the end of 2018. In December 2018, given the obligation to speed up the EU clean energy transition a new Directive, the recast RED II, established an improved new target of 32% RES share of renewable energy and at least 40% greenhouse gas emissions abatement objective by 2030, relative compared to 1990 levels.

More than a decade after the first RED, amidst the 25th session of the Conference of the Parties (COP) in December 2019, the European Commission's President Ursula von der Leyen presented the European Green Deal (EGD). This legislative piece outlined the European's playbook to meet objectives more ambitious than those stipulated in the Paris Agreement. The document highlights the critical state of

27 S&P Global Commodity Insights (2023), Key trends for India's power and renewables markets in 2023, https://www.spglobal.com/commodityinsights/en/ci/research-analysis/key-trends-for-indias-power-and-renewables-markets-in-2023.html.



the environment and recognizes the existential threat that ecological tipping points pose to humanity.

Therefore, the main mission of the document is to reach climate neutrality in Europe by 2050, and remarks that environmental ambitions in line with the Paris Accord will not be achieved unless there is a global effort to rapidly abate greenhouse gas emissions. Consequently, the Green Agreement pledges to use the European Union's influence, knowledge and financial resources to encourage world nations to propose similar plans to reach zero net emissions by 2050.

Together with the European recovery plan and the EU budget, the EGD serves as a framework for the EU to leverage short and long-term actions for a clean, resilient and just transition away from fossil fuels. The EGD aims at accelerating investments and technological progress required for the long-term decarbonisation of the EU. Furthermore, it establishes a regulatory playing field that provides consistency of EU policies, to promote industrial transformation, technology, and innovation leadership.

To achieve the goals set by the EGD, the Commission committed to mobilising at least €1 trillion in sustainable investments until 2030. Over half of the budget, €528 billion is directly sourced from the EU multiannual budget (2021-2028) and the EU Emissions Trading System. The remainder will be obtained from the InvestEU programme which procures €279 billion from the public and private sectors and €114 billion from national co-financing. The European Innovation Council has also set aside €300 billion to fund market-creating innovations that contribute to the goals of the EGD. To ensure that the energy transition unfolds fairly, a Just Transition Mechanism is also created to invest €100 billion in the regions and sectors most affected by the transition.

In July 2021, the Commission proposed another revision of the RED, increasing the target to 40% as part of the 'Fit for 55' package aimed at streamlining the delivery of the European Green Deal. However, less than a year later, in light of the Russian invasion of Ukraine and the necessity to address serious energy security concerns, the EC launched on in May 2022 the 'REPower EU Plan'. This policy package represents the backbone of the EU's roadmap to end EU dependence on imported Russian fossil fuel imports.

The main areas of action of the plan are: energy efficiency and savings; energy supply diversification; clean-energy transition acceleration; and backstop solutions in case of a sudden interruption of Russian gas supplies. The EC estimates the delivery of the REPower EU goals requires an additional investment of €210 billion between 2022 and 2027. However, the success of the plan is dependent on EU-27 countries as proposed measures require either national implementation or coordination among members.

Aligned with these objectives, the EC proposed to further increase the RED II target, from 40% to 45% by 2030. In March 2023, a provisional agreement was reached for a 42.5% binding target for 2030 of at least 42.5% but aiming at an aspirational 45% target.

5.2.3.1. The Solar Strategy

As part of the 'REPower EU Plan', the EC adopted the first-of-its-kind EU Solar Strategy, which aims to provide the right framework to massively accelerate deploy solar PV energy deployment to reach and sets out new targets of 400 GW by 2025 and 750 GW of installed solar PV capacity by 2025 and 2030 respectively. Specifically, the EU Solar Strategy addresses three key elements.

Firstly, the tapping of the vast and underutilised rooftop solar potential of rooftops for solar PV systems, by gradually introducing an obligation to install solar technology in new and renovated buildings over the next years. Secondly, resolving the EU solar skills gap in the EU by promoting the development of a skilled pool of workers in the solar sector. Lastly, the creation of a new European Solar PV Industry Alliance to reach 30 GW of committed European manufacturing capacity across the entire PV value chain annually by 2025, across the entire PV value chain. The alliance is a platform for stakeholders in the sector focused on securing investment opportunities for European solar PV production and enabling diversification of the supply chains, retaining more value in Europe and delivering efficient and sustainable domestic industry. According to the EC, reaching this objective would deliver €60 billion of new GDP every year in the EU and the creation of more than 400,000 jobs.

5.2.3.2. The Solar Manufacturing Strategy

The solar sector in Europe has witnessed drastic changes over the last decade. Europe kicked off the 2010s as a solar PV powerhouse. Then, the EU reacted to a ramped-up Chinese industrial policy with import tariffs on solar panels, which did not help Europe's solar manufacturers, and contributed to a steep decline in European solar rollout.

The 2020s represent a new era of solar growth and the EU targets the build-up of a new solar industrial base. There is now a strong political awareness of the need for clean tech industrial strategies. Subsequently, more open discussions are taking place on Europe's competition rules and State Aid policy. The US Inflation Reduction Act has been the catalyst for this changed approach. The IRA is the latest – and probably most impactful - in a series of assertive industrial strategies on solar manufacturing proliferating around the world, following developments in India, Turkey, and of course the most successful example, China. This series of manufacturing strategies are accelerating the global competition for solar PV value chains outside of Europe. In response, the EC announced in January 2023 the Green Deal Industrial Plan (GDIP), a multi-pronged scheme to drive renewable energy and clean technology development, covering four key pillars: the regulatory environment, financing, skills, and trade.

The first pillar introduces the Net Zero Industry Act (NZIA), which proposes measures to strengthen clean technology manufacturing in the EU towards the overall aim of domestically manufacturing at least 40%. Alongside the NZIA, the Critical Raw Materials Act targets refining, processing, and recycling rare earth metals and raw materials that are imperative for producing renewable technology.

The second pillar sizably augments the investments and financing possibilities for the onshoring of the renewable manufacturing industry. It temporarily alters state rules to fast-track and simplifies the process of EU financing for member states by providing simple tax breaks and targeted aid for production facilities. As mentioned above, the EC launched the European Industry Solar PV Industry Alliance to promote even further investments in domestic manufacturing of solar technology.

The third pillar of the GDIP revolves around enhancing skills needed in the energy transition, by rolling out up-skilling and re-skilling programmes in strategic industries. According to the trade association SolarPower Europe, in 2021, more than 450,000 full-time workers were employed in the EU solar industry and would need to more than double the current workforce by the end of the decade to reach the solar targets.

Lastly, the GDIP centers on open trade for resilient and diversified supply chains with EU partners to support the region's green transition. It also explores the creation of a Critical Raw Materials Club that connects nations that supply these resources with raw material consumers to secure a safe sourcing flow through a competitive and diversified industrial base, along with clean technology and net-zero industrial partnerships.

5.2.3.3 Impacts on the Solar Industry

Ever since the EGD established the regulatory framework for solar PV to regain traction in the EU, the solar market has grown consistently. In 2019, the solar capacity in the region experienced a more than 100% growth relative to 2018, by adding nearly 17 GW of solar power to reach 119 GW of total capacity. In 2020, the COVID-19 pandemic adversely affected the ongoing upward trend of the

sector but installations still kept on the rise, growing by 19% and grid-connecting almost 20 GW. 2021 was a record-breaking year as the solar EU market expanded by 41% and added 28 GW to reach 167 GW of cumulative capacity.

In 2022, despite soaring inflation and interest rates, improved regulatory conditions for solar and an energy crisis that provoked many consumers to turn to solar, the 27 EU Member States saw 41.4 GW of new solar PV capacity connected to the grids, a 47% increase compared to 2021. At the end of the year, the cumulative capacity stood at around 207 GW of solar. Overall, many factors contributed to the spectacular growth of solar in the EU, but the trust that EU policymakers put in the potential of solar positively contributed to this ongoing upward path of demand.

In terms of supply, the EU faces a potential supply resiliency risk as it relies almost entirely on imports from China. With solar PV manufacturing heavily concentrated in China and Southeast Asia, the EU has imported 84% of its installed solar PV modules over the last five years[28]. While European companies initially led the industry, Chinese solar-PV companies today dominate both manufacturing at scale and deploying new technologies, supporting major solar-PV ecosystems built around industry hubs.

However, as the EU has painfully learned, potential supply chain risks pose an enormous economic threat and it has begun its solar-PV strategy to reestablish a viable PV manufacturing industry. According to SolarPower Europe, the EU solar PV industry has around 9.5 GW of module production capacity, 1.4 GW of cells production, 1.7 GW of ingots and wafers, and 23.2 GW of polysilicon manufacturing. For other components, the EU produces a much larger share of inverter demand with 70 GW of manufacturing capacity.

The EU solar manufacturing industry faces two major hurdles that may endanger the proposed manufacturing goals. Firstly, electricity prices are much higher now due to the ongoing energy crisis, which increases production costs and makes it less attractive to produce solar PV technology in the EU. The IEA revealed that costs in China are 35% lower than in Europe due to lower construction and development timelines, labour and material costs, higher costs of capital, and lack of economies of scale in Europe. Secondly, as the US and India progress with their new massive policies to scale up PV manufacturing, EU solar producers fear that the continent will become less competitive as a result of less ambitious regulation.

On the positive side, although the solar industry is currently small, it does not have to start from scratch, as the sector possesses the knowledge, the skills and the enduring components across the supply chain. The crucial missing ingredient is scale. Nonetheless, research shows that a sufficient production capacity and a European supply chain would make vertically integrated production in the EU globally competitive[29]. One additional where EU manufacturers might gain a competitive advantage is by producing modules with a lower carbon footprint, absolute compliance with human rights, and circular design of products. The use of non-price criteria in renewables auctions or price premiums for these environmental and social standards rewards EU manufacturers for their higher efforts in those dimensions and effectively creates market differentiation for consumers with a higher willingness to pay for more sustainable and ethical solar technology.

28 IEA (2022), Solar PV Global Supply Chains, IEA, Paris https://www.iea.org/reports/solar-pv-global-supply-chains, License: CC BY 4.0

29 Fraunhofer ISE (2020), Sustainable PV Manufacturing in Europe, https://www.ise.fraunhofer.de/en/publications/studies/sustainable-pv-manufacturing-in-europe.html.

Note

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