EPJ Photovoltaics **14**, 23 (2023)

https://doi.org/10.1051/epjpv/2023016

Available online at:
www.epj-pv.org

VIEWPOINT

OPEN ACCESS

Snapshot of Photovoltaics – May 2023

Arnulf Jäger-Waldau*

European Commission, Joint Research Centre (JRC), Via E. Fermi 2749, 21027 Ispra (VA), Italy

Received: 22 May 2023 / Received in final form: 19 June 2023 / Accepted: 26 June 2023

Abstract. In 2022 the cumulative installed photovoltaic electricity generation capacity increased to over 1 TW, 10 years after it reached the 100 GW level in 2012. In 2022, overall investment in renewable energy has increased by 16% to USD 499 billion compared to USD 953 billion for fossil fuels, which saw an increase of 6%. Investments in solar photovoltaics accounted for USD 301.5 billion or 60% of the renewable energy investments. The annual installations of solar photovoltaic electricity generation systems increased by about 40% to over 230 GWp in 2022. Compared to 2021, the number of countries which installed 1 GWp/year or more has increased by almost 80% to 32. Despite the increase in hardware costs for solar photovoltaic systems and battery storage, both markets had a strong growth, driven by the soaring energy prices in 2022. The increase of the levelised costs for solar photovoltaic electricity was well below the increase of electricity generated with fossil fuels. The electrification of heating, transport and industry will create additional demand for renewable electricity, including solar, if we want to stay on track for not more than 1.5 °C global temperature increase.

Keywords: Renewable energies / photovoltaic / green hydrogen / energy challenge / policy options / technological development / market development

1 Introduction

The publication of the 6th Intergovernmental Panel on Climate Change (IPCC) assessment report in April 2022 [1] and the geopolitical developments since February 2022 have highlighted the need and urgency for a clean energy transition.

Due to the higher efficiency of electric technologies compared to fossil fuel-based solutions, which provide similar energy services, the 2022 IEA electricity report acknowledges the great potential to reduce final energy demand by electrification [2]. The report also states that electrification goes hand in hand with an increase of renewable energy and therefore contributes significantly to emission reduction.

According to the net zero by 2050 scenario (NZE) of the IEA, electricity supply will increase from 28,334 TWh in 2022 to 37,723 TWh in 2030 (+33%) and 73,232 TWh in 2050 (+158%) [3,4]. It is expected that the renewable energy generation will increase from 8,349 TWh in 2022 to 10,799 TWh (+29%) by 2025, surpassing coal as the major fuel for electricity generation [5]. Solar and wind will contribute the lion's share of the increase of 2450 TWh in renewable energy generation. This is an acknowledgement of the fact that neither solar nor wind resources can be monopolized by one country. Solar photovoltaics (PV) can be deployed in a modular way almost everywhere on this planet from installations with a few Wp capacity to multi GWp solar plants.

It is worthwhile to note that compared to the World Energy Outlook (WEO) 2021, the modelled electricity supply of solar photovoltaics (PV) by 2030 in the WEO 2022 has increased from 6970 TWh to 7551 TWh (+8.3%) and from 23,469 TWh to 27,006 TWh (+15.1%) by 2050 [6]. The corresponding capacities are given as 5.05 TW in 2030 and 15.47 TW in 2050. However, if the same electricity generation to production capacity conversion factors as in the WEO 2021 are used, this would require an installed PV capacity of 5.54 TW in 2030 and 16.67 TW in 2050. Why the power electricity? Generation for a PV system per unit nominal power has increased from WEO 2021 to WEO 2022 is not explained in the report. One explanation could be that the capacity numbers used in 2022? Are AC and not nominal (DC) power. As already mentioned in the 2022 Snapshot, from all scenarios presented by the IEA, only the "Net Zero Emissions by 2050" scenario is in line with the target to limit the global temperature increase to 1.5 °C [7].

Between 2017 and 2021 energy investments accounted for roughly 2% of global GDP. To realise the NZE these would have to increase to 4% by 2030, i.e. from USD 2 trillion to USD 4 trillion. According to the IMF, current

*e-mail: arnulf.jaeger-waldau@ec.europa.eu

Uncertainty in reported capacity numbers

Not all countries report standard nominal power capacity for solar PV systems (DC or Wp under standard test conditions), but the inverter or electrical connection capacity, which is in AC. Over the last decade the so called "overpowering", i.e. when the DC capacity is larger than the AC capacity, has increased from 1.1 to almost 2. In 2022 constructed larger PV plants have a DC/AC ratio of 1.1 to 1.6, which means that the nominal capacity can be 10–60% higher than the reported AC capacity [8]. Overpowering of PV systems leads to a longer utilization of the full connection capacity and can be cheaper than the installation of electricity stabilisers to maintain steady supply at the required power.

Looking at energy scenarios, energy modelers are only interested in AC capacity, since the electricity network is AC. Therefore, significant differences can exist in the actual needed nominal power of PV systems, which determines the number of modules needed, and the modeled network capacity.

The reported capacity numbers of PV installations in this paper are given in nominal DC power or Wp. Production volumes are reported here in Wp as well. Where national statistics report capacities in AC, a conversion factor based on industry information and project descriptions is used.

annual direct and indirect government subsidies for fossil fuels are almost 50% higher at USD 5.9 trillion [9]. Environmental costs and foregone consumption taxes are included in this amount.

In 2022 global investments in energy transition technologies have surpassed USD 1.1 trillion [10]. In addition more than USD 270 billion were invested in power grids, which are an important component to enable the energy transition, but serve conventional power generators as well. However, compared to global investments into fossil fuels of USD 1.1 trillion, still less than half is invested in renewable energy with USD 495 billion (45%). Investments in solar energy was USD 307.5 billion, whereas photovoltaics accounted for USD 301.5 billion and concentrating solar power contributing about USD 6 billion [10,11].

But is the NZE enough? Independent modelling from various research groups project much higher needs for PV installations and range between 50 and 65 TWp by 2050 [12–14]. These scenarios assume a balance between climate costs and the UN development goals. The needed capacity will increase significantly if the demand for heat production and transport as well as industrial needs and desalination are considered as well [15].

2 PV solar cell production

The global cell production[1] during 2022 was in the range of 350 GW to 370 GW; and is expected to increase again by 20–30% in 2023. The uncertainty in this data is due to the highly competitive and shifting market environment, as well as the fact that some companies report shipment figures, some report sales, while others report production figures. A detailed description of the uncertainties in production and deployment statistics has been published in earlier versions of this report [16].

Data were collected from stock market reports of listed companies, press announcements and market reports and were then cross checked. For 2022 this led to an estimate of 367 GWp about 50% more than in 2021 (Fig. 1). Numbers from previous years were updated where necessary. According to Paula Mints, manufacturer shipments increased from 194-GWp in 2021 to 283.1 GWp (+46%) in 2022 [17].

The increase in manufacturing capacity along the whole solar photovoltaic value chain is still outpacing market growth. In March 2023, Bloomberg New Energy Finance reported that they tracked over 600 companies along the crystalline silicon value chain i.e. polysilicon, wafer, solar cells and module manufacturing and 23 non-silicon thin film companies [18]. In 2022, the manufacturing capacity of silicon solar cell increased to about 458 GWp, whereas that for non-silicon thin films increased to 11 GWp. In March 2023, an additional capacity of 111.9 GWp for silicon solar cells and 6.3 GWp for non-silicon thin films were under construction. The announcements of new capacities exceeded 300 GWp for silicon solar cells and 9 GWp for non-silicon thin films.

At the end of 2022, close to 1,200,000 metric tonnes polysilicon manufacturing capacity were operational and another 538,000 metric tonnes were under construction in March 2023. An additional 1,986,000 metric tonnes of polysilicon production capacity are announced. Just the already operational capacity would be able to produce polysilicon for 461.5 GWp of silicon solar cells under the assumption of 2.6 g/Wp silicon usage rate.

At the current pace of manufacturing capacity expansions in the solar industry, the needed production capacity of 820 GWp for the NZE WEO 2021 scenario, foreseen for 2030, can be achieved by the end of 2025. If the industry can maintain a 25% annual manufacturing capacity increase from 2025 to 2030, total could reach 2.5 TWp by 2030, consistent with that needed for a 100% renewable energy scenario by 2050 [15,19,20].

[1] Solar cell production capacities mean:
– In the case of wafer silicon based solar cells, only the cells.
– In the case of thin-films, the complete integrated module.
– Only those companies which actually produce the active circuit (solar cell) are counted.
– Companies which purchase these circuits and make cells are not counted.

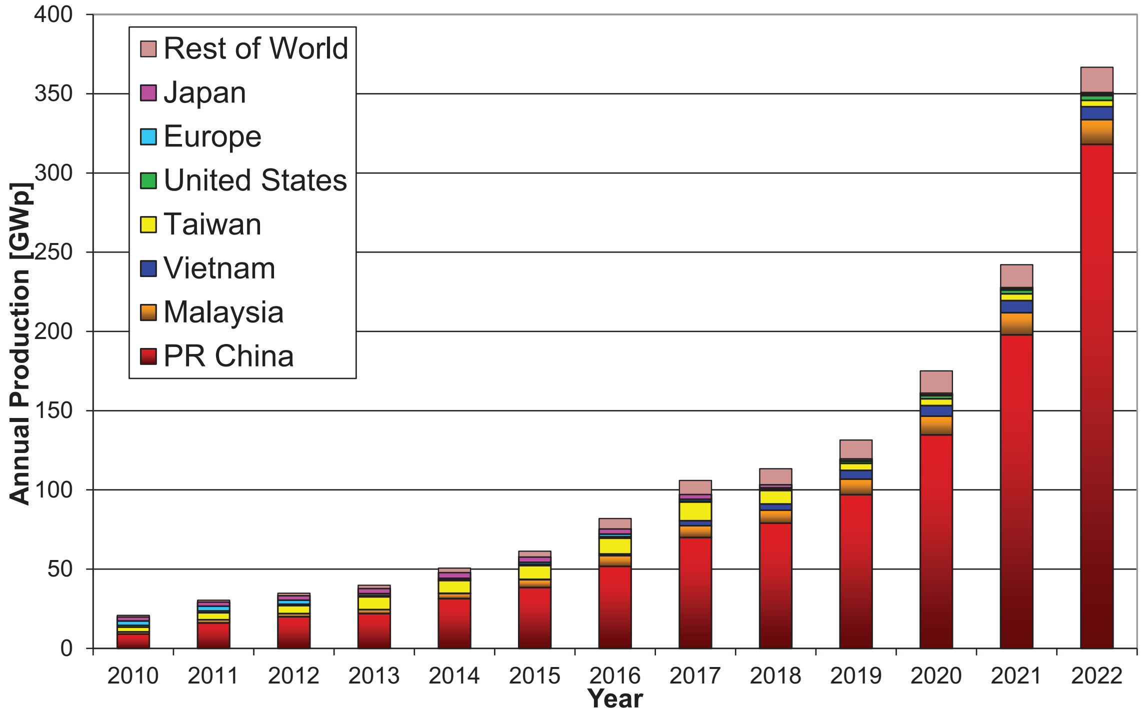

Fig. 1. World PV Cell/Thin Film Module Production from 2010 to 2022.

Such an increase looks realistic, especially as PV manufacturing growth is now being pursued more seriously in Europe, India and the USA.

Very often concerns are raised that such a manufacturing growth could not be realised due to a shortage of critical raw materials. However, numerous studies have shown that the availability of material would not be a showstopper for the multi TW growth of the PV industry, due to the availability of alternative routes in solar cell and module design [21]. Silicon, which is used for more than 95% of all solar cells, is of the most abundant materials on Earth. Nevertheless, one has to keep an eye on the economic availability of high purity quartz (SiO_2 with 99.99%+ purity), that is used to manufacture crucibles for CZ single crystal silicon growth and silica sand for polysilicon production [22]. Silica sand is also used for in the glass industry, which also produces solar glass for PV modules. In addition, contact materials like silver, indium and bismuth are often cited as a limiting factors. In order to reduce the quantities of these material used per Wp, intensive industry research and technology development is conducted [23]. Research and technology progress leads to a constant increase of solar cell efficiency as well as a better understanding of alternative contact materials. For some thin film technologies, production volumes could be limited [24,25]. Overall, modern module designs using circular manufacturing concepts and material reduction for the balance of system is of equal importance to achieve the required grow of the PV industry.

3 Solar PV electricity generation and markets

The trend for global convergence of PV solar system CAPEX continued during the last year, despite elevated material costs and increased fuel prices. Of course local factors like market size and maturity, import taxes, local content rules or existing tax credits have an influence on local prices, and can still lead to significant price variations.

In the first half of 2022, the global benchmark LCOE (levelized cost of electricity) for electricity produced by PV systems increased significantly, but, in contrast to the situation for fossil power, it decreased for non-tracking PV systems in the second half of 2022 [26,27]. At the end of 2022, it showed an overall increase of 12% compared to 2021 and stood at USD 45 per MWh. The full range of LCOE for non-tracking PV systems varied between USD 27 to 229 per MWh. The increase in the upper limit was very often due to a weakening of the local currency against the USD.

Similar, the global cost benchmark for tracking PV systems increased by about 13% to USD 44 per MWh. This development was driven mainly by price increases in the USA, which saw higher balance of plants material prices, increased transport costs and higher module prices due to alternative sourcing of solar modules triggered by trade frictions with China.

Compared to the freight cost peak in Q3 2021 (six fold increase compared to H1 2020), freight rates in Q4 2022 have decreased significantly and were on average about 30% higher than in the first half of 2020.

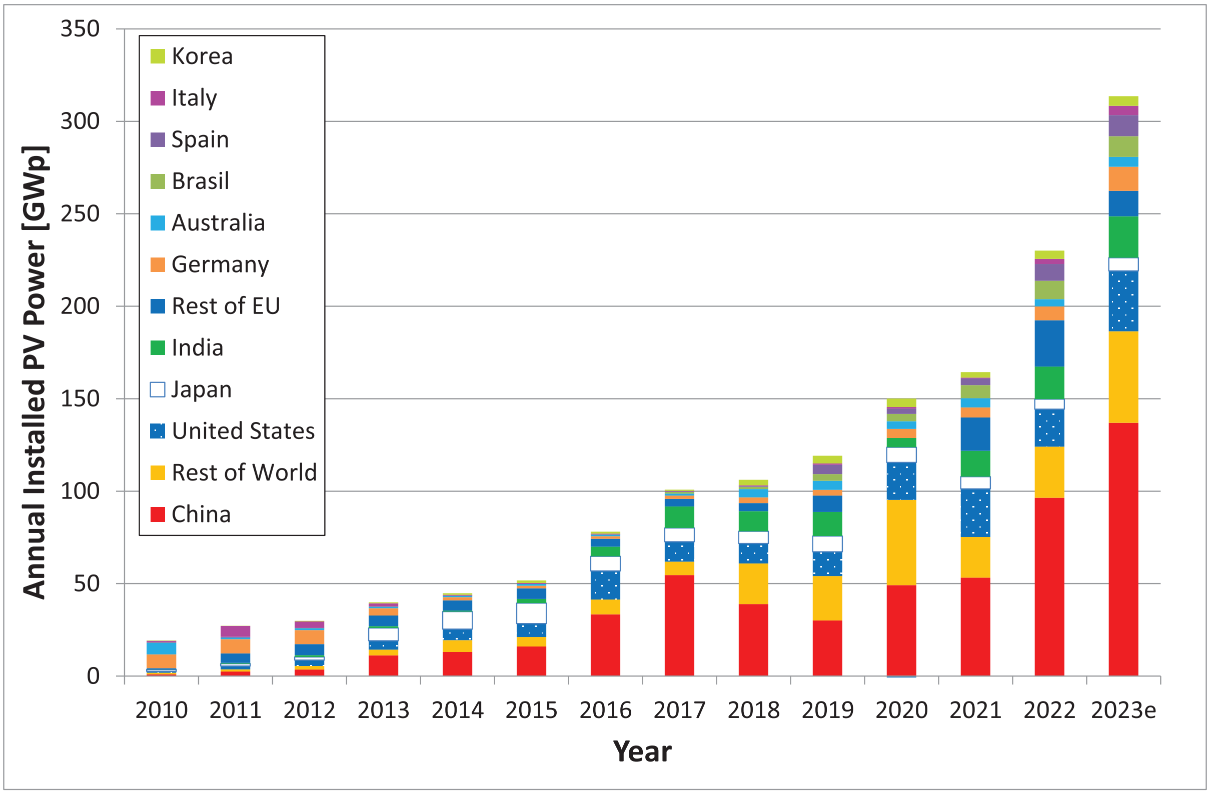

Fig. 2. Annual photovoltaic installations from 2010 to 2022 with estimates for 2023 (data source: [8,17,33] and own analysis).

After a decade long decline of lithium-ion battery pack prices with a learning rate of 18% and a price decrease of 89% to USD 141/kWh in 2021, battery pack prices increased in 2022 by 7% to USD 151/kWh [28]. It is expected that prices in 2023 will remain around the same level, before they will start do decline again in 2024 and 2025. The global benchmark for levelised cost of electricity storage (LCOES) for a 4-hour storage system increased by 19% to USD_{2021} 169/kWh.

Investments in electricity storage increased by USD 5 billion to USD 15.7 billion in 2022. About 30% of these investments were for residential PV and 11% for commercial PV systems [10]. Leading markets include Australia, China, Germany, Italy, Japan, South Korea and the USA. The main motivation for an investment into a storage system, despite a significant CAPEX increase, were concerns about resilience to grid power disruptions, high grid electricity prices and a growing interest in the self-use of solar power.

The investment into storage systems for large scale PV plants is driven by factors like the increase of usage hours of the AC connection, access to time dependent offtake contracts or auctions, i.e. participation to new market segments at times without solar radiation and guarantee of power quality during ramp times. In 2022, 16 GW (35 GWh) of storage were added, which is an increase of 68% compared to 2021 [29]. According to industry analysts, the storage market is expected to grow with a CAGR of 23% between 2023 and 2030, to reach an annual market size of 88 GW (278 GWh) and a cumulative installed storage capacity of 530 GW (1.4 TWh) by the end of 2030.

The global PV LCOE benchmark only shows the general trend. Real local electricity generation costs are determined by a set of additional local factors. These include geographical and technology factors like solar radiation, tracking or no-tracking PV system design, string or central inverter configuration, fixed operation and maintenance (O&M) as well as connection costs. The financing costs of a PV project whether it be large scale, commercial or residential has a significant impact on the final electricity generation costs [30]. Interest rates, local currency fluctuations against the USD, the ratio between debt and equity including the expected returns on equity, have great influence and vary significantly from country to country. Therefore, to attract investors to solar energy, stable and reliable long term conditions are crucial. Competition in electricity markets and the ability to freely participate in this market is another key factor that influences investments and financing costs for new PV installations [31].

In 2022, overall investment in renewable energy increased by 16% to USD 499 billion [10]. Investments in photovoltaics increased by 47% and accounted for USD 301.5 billion or 60% of the renewable energy investment. New PV capacity increased by about 40% to over 230 GWp in 2022 (Fig. 2), which is at the lower end of the conservative (228 GWp) and optimistic forecasts (252 GWp) [32,33]. For 2023, market forecasts are considerably higher, with an annual new installed capacity estimates above 300 GW, which would bring the total cumulative installed PV capacity to 1.5 TWp (Fig. 3).

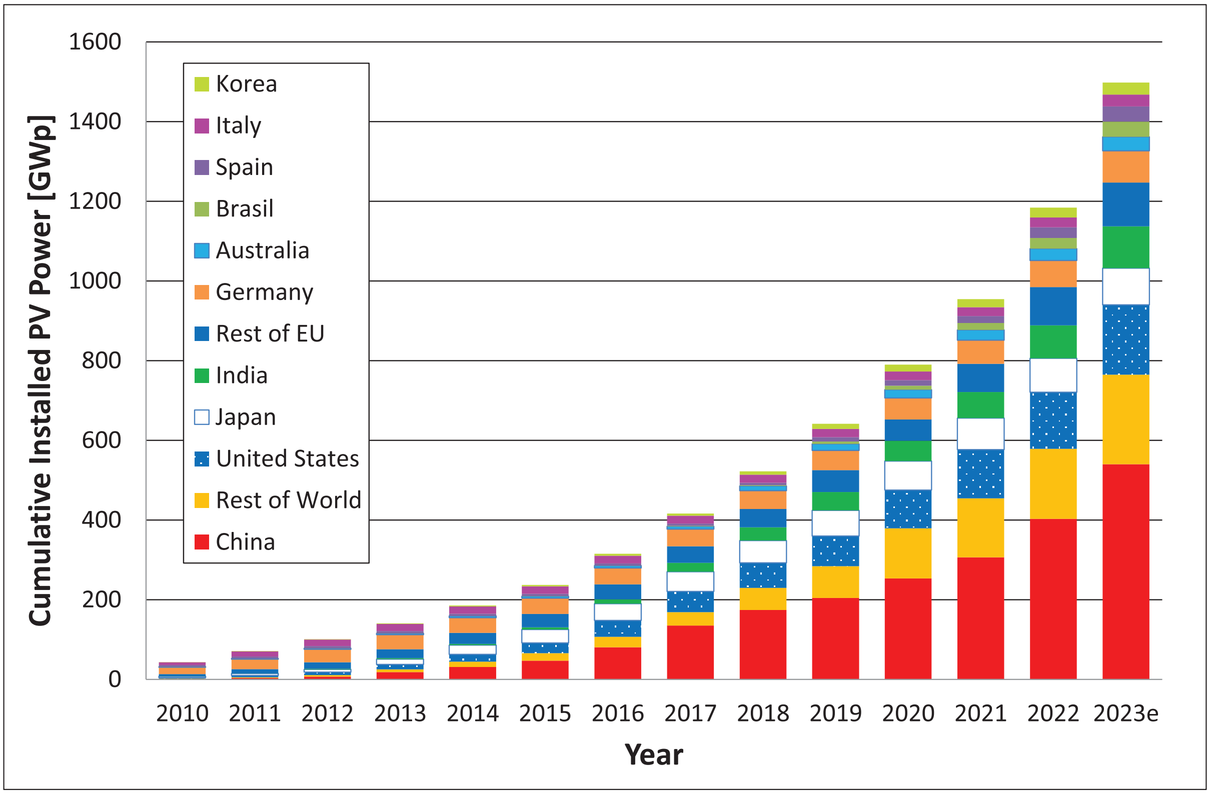

Fig. 3. Cumulative Photovoltaic Installations from 2010 to 2022 with estimate for 2022 (data source: [8,17,33] and own analysis).

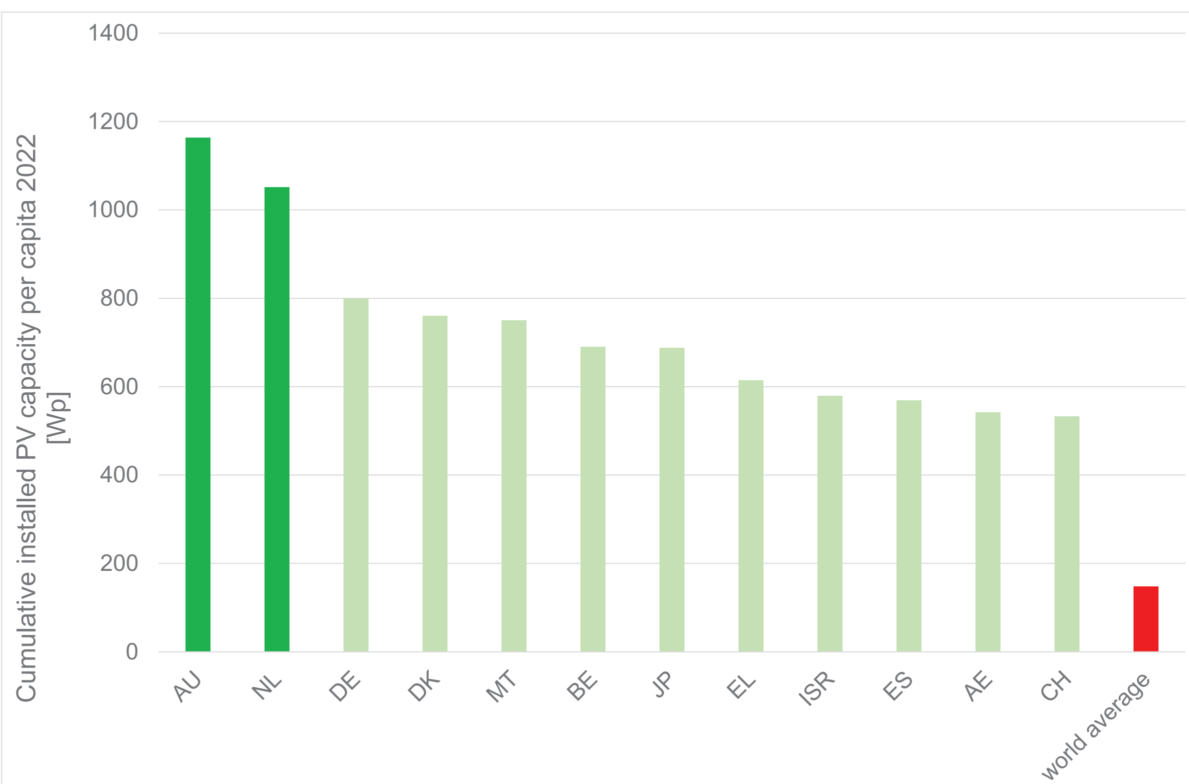

Fig. 4. Countries with a cumulative photovoltaic capacity of at least 500 Wp per capita and the world average value. (Data source: [8,17,33] and own analysis).

Table 1. World-wide scenarios of cumulative solar photovoltaic electrical capacities until 2040. With the exception of the LUT scenarios the future projections are AC capacity.

Year	2022 [GWp]	2025 [GW]	2030 [GW]	2040 [GW]
Actual Installations	1185			
Greenpeace (advanced [r]evolution scenario)		2000	3725	6678
LUT 100% RES Power 2017		3513	6980	13,805
LUT 100% Energy 2019		3528	12 951	30,531
BNEF NEO 2020		1534	2382	5009
IRENA 2019 reference case*		1020	2017	3122
IRENA 2019 REmap case*		1358	3151	5761
IEA Stated Policy Scenario 2022**		1491	3020	5573
IEA NZE Scenario ** 2021		1916	4956	10,980
IEA NZE Scenario ** 2022		1938	5052	11,620

* 2025 values are interpolated, as only 2016, 2030 and 2040 values are given.
** 2025 value is interpolated, as only 2020, 2030 and 2040 values are given.

China has a cumulative installed capacity of more than 400 GWp, representing roughly one third of the total global 1185 GWp installed PV capacity. The European Union follows with about 18% or 211 GWp and the USA with over 142 GW (12%) (Fig. 3).

The data in Figures 2 and 3 only takes into account the absolute capacity, without considering the the actual population or land area. Figure 4 shows the twelve countries, which had installed more than 500 Wp per capita at the end of 2022. The world average however stood at only 148 Wp per capita. However, even to reach the modest NZE targets of the IEA the world average would need to increase to 652 Wp per capita in 2030 and 1,755 Wp in 2050.

Africa: Over the last decade, the total installed solar PV capacity has increased by two orders of magnitude from about 220 MW in 2012 to over 18 GW at the end of 2022. 21 African Nations are now home to more than a 100 MWp of PV capacity. South Africa, Egypt and Morocco all have more than 1 GWp and together they account for about 53% of the total capacity. Despite the continent's vast solar resources, hydropower is still the largest source of renewable electricity generation and supplies about 17% of the demand [34]. However, changing patterns in rainfall and temperatures caused by climate change could not only hamper future expansion, but reduce the power generation of existing plants as well. Combining existing hydropower plants with floating PV on their reservoirs could help to better utilise the existing hydro resources and enhance the economic performance of the plants. If just 1% of the reservoirs' area would be covered with floating PV, it would increase the electricity power output of these plants by 50% [35].

One of the successful tools to finance large scale solar PV projects in Africa is the World Bank's Scaling Solar programme [36]. Seven African Nations, Côte d'Ivoire, Ethiopia, Madagascar, Niger, Senegal, Togo and Zambia have signed financing agreements and plants in Madagascar, Senegal and Zambia have already been realised.

The "Desert to Power" initiative was launched by the Africa Development Bank (AfDB) in 2018. The initiative aims to deploy 10 GW solar power for the 250 million people across the Sahel zone. The first AfDB grants under the Sustainable Energy Fund for Sustainable Africa (SEFA) were released in December 2020 with a value of USD 6.5 million [37]. However, most of the projects in Chad, Burkina Faso, Niger, Mauritania and Mali are still in the planning or construction phase and not yet operational.

The Benban solar complex, located near Aswan in upper Egypt, with 2 GW_{AC} power is still the largest solar project in Africa. It consists of 41 individual plants, of which 31 have a 50 MW_{AC} (64 MW_{DC}) capacity, whereas the remaining 10 projects have different capacities, due to the shape of the available sites [38].

Americas: North and South American countries added new solar photovoltaic power capacity of about 36 GWp in 2022. This was about 12% less than in 2021, mainly due to import tariif uncertainty in the first half of 2022 and the postponement of projects in the USA to profit from the Inflation Reduction Act (IRA) signed in the fall of 2022 [39]. The three largest markets in 2022 were the USA (over 18 GWp) Brazil (9.9 GWp) and Chile (1.9 GWp). Currently, the Americas have an overall installed capacity of 201 GW, of which about 70% is in the USA alone. For 2023, market forecasts indicate the possibility of adding more than 50 GW.

According to Solarbe Global between 16 and 17 GWp of PV capacity is expected to be added across Latin America in 2022 [40]. Most of this capacity is expected to be installed in Brazil, followed by Chile and Mexico.

Asia & Pacific Region: In 2022, China changed its national reporting system from nominal capacity to AC capacity. This created some difficulties to convert the reported capacity of 51 GW_{AC} residential/commercial systems and 36.1 GW_{AC} large scale systems [41] to GWp. Under the assumption that residential and commercial systems have no overpowered capacity, this would give a value of 51 GWp for the residential/commercial systems. Under the assumption of an average overpowering ratio of

1.3 (an average between lower and higher overpowering) results in 47 GWp for large scale systems. The total then is 98 GWp.

India had a strong performance and added over 18 GWp of new solar photovoltaic installations. Again, most of this capacity were large scale plants and in the rooftop segment, which accounted for about 10%, with commercial and industrial applications dominating this market segment. Stable markets in Australia, Israel, Japan, Pakistan, South Korea, the United Arab Emirates and Vietnam helped the Asian-Pacific PV market grow by 59% to 138 GWp. For 2023, a growth of up to 40% is possible, which would lift the annual market close to the 200 GWp level.

European Union: In March and May 2022, the European Commission published the REPowerEU Communication and the Solar Strategy Communication respectively [42,43]. REPowerEU aims to reduce net emissions by at least 55% by 2030 and the Solar Strategy called for an additional photovoltaic capacity of 450 GWp between 2021 and 2030, which would mean a roughly fourfold increase of the nominal capacity to over 720 GWp by 2030.

In 2022, the photovoltaic market in the European Union grew by over one third to more than 40 GWp and reached a cumulative installed capacity of about 211 GWp. Compared to 2022, the Solar Strategy would require an annual market volume increase to over 100 GWp annually by 2030, which is achievable if the current market trend can be maintained [44].

In October 2022, the European Commission endorsed the creation of a new European Solar Industry Alliance, similar to the already existing Battery Alliance, which was launched in 2017. The Solar Industry Alliance will support the objectives of the EU's Solar Energy Strategy, an essential component of the REPowerEU plan, which set out how to massively scale-up and speed-up the production of renewable energy in Europe to regain its independence from Russian fossil fuels, and make its energy system more resilient.

The annual market in the European Union grew almost 60% to over 40 GWp in 2022. Already twelve countries have installed more than 1 GWp cumulative capacity and recorded significant further increases in 2022, namely Spain (8.0 to 8.2 GWp), Germany (7.4 to 7.6 GWp), the Poland (4.8 to 5.0 GW), Netherlands (3.8 to 4.0 GWp), France (2.6 to 2.8 GWp), Italy (2.5 to 2.7 GWp), Portugal (2.4 to 2.6 GWp), Denmark (1.4 to 1.6 GWp), Greece (1.3 to 1.5 GWp), Austria (1.2 to 1.4 GWp), Belgium and Sweden (1.0 to 1.2 GWp) each. Several EU countries with previously moderate PV instalment rates became hotspots for rapid PV development in last 2 years like Austria, Italy, Portugal and Sweden.

In terms of installed capacity per capita, the Netherlands are leading in the EU with 1051 W_p, second globally only to Australia with 1168 Wp. Seven EU countries have more than the European Union average of 475 Wp per capita, namely, the Netherlands (1051 Wp), Germany (800 Wp), Denmark (760 Wp), Malta (750 Wp), Belgium (690 Wp), Greece (614 Wp), and Spain (558 Wp). So far, only five countries have not yet installed at least 100 Wp per capita.

4 Conclusions

In many countries and regions around the globe, solar photovoltaic electricity generation already offers the lowest cost power. Nevertheless, photovoltaic technology still has a considerable cost reduction potential along the whole value chain. The increasing deployment of battery storage in combination with photovoltaic electricity generation provides dispatchable power and, in a growing number of cases, the most economic solution as well. A shift towards the electrification of our energy use, including the electrification of heating as well as transport, together with the overall need to provide CO_2 free energy, is driving the growth of PV installations. After achieving a cumulative installed PV power capacity of more than 1 TWp in 2022, it is expected that the 2 TWp mark can be reached by 2025.

Various PV industry associations, financial consultants, non-governmental organisations (NGOs) and supranational organisations, like Greenpeace, the Energy Watch Group, Bloomberg New Energy Finance (BNEF), the International Energy Agency as well as the International Renewable Energy Agency (IRENA), have developed scenarios for the future growth of PV systems as shown in Table 1 [3,6,45–49]. References to earlier scenarios can be found in earlier versions of the PV Snapshot.

A significant growth of PV power capacity in the future is predicted by all scenarios, regardless of the existing differences in the deployment pathways and ambitions. Total electricity generation in 2021 was 27,813 TWh and would have required a PV capacity of about 20.2 TWp. To install this capacity would use approximately 0.3% of the world's land area or 30% of the global settlement area [50]. Over the last years studies have identified huge potentials to install PV on rooftops, facades, with dual use of infrastructure, on brownfield sites or novel applications like agri-photovoltaics or floating PV systems [35,51–57].

The challenge is to muster the support of all stakeholders and to put an enabling policy framework in place. In order to make the energy transition work, fundamental system changes are needed. The acceleration of renewable energy use, storage build up and market changes are necessary and this will not happen by themselves. Our societies have to accept the fact that more effort is needed to realise the energy transition and to stay on a pathway for a maximum of 1.5 °C global temperature increase. This is not an easy task and the window of opportunity to stay on track is narrowing every day.

The technical characteristics of solar photovoltaics, its modularity, a very low CO_2 footprint (based on a full life cycle analysis), "no emission no pollution" make it a perfect solution for dense urban environments and a crucial pillar for realizing a net zero carbon energy supply by 2050 [58].

However, there are still barriers ranging from perception, legal and regulatory conditions as well as technical limitations of the existing transmission and distribution systems to be overcome. So far, neither the necessary adaptation and transformation of the energy networks, nor changes of electricity market business models nor the political will to accelerate the use of renewable energy sources such as PV is in line with the urgency to decarbonise our energy supply by 2050.

Disclaimer

The views expressed are based on the current information available to the author and may not in any circumstances be regarded as stating an official or policy position of the European Commission.

References

1. Intergovernmental Panel on Climate Change. IPCC Sixth Assessment Report, WG III. 2022. Available online: https://www.ipcc.ch/report/ar6/wg3/
2. International Energy Agency. Electrification, IEA, Paris, 2022. Available online: https://www.iea.org/reports/electrification
3. International Energy Agency. World Energy Outlook 2022, OECD Publishing, Paris, 2022. Available online: https://doi.org/10.1787/3a469970-en
4. International Energy Agency. Net Zero by 2050–A roadmap for the Global Energy Sector, 2021. Available online: https://www.iea.org/reports/net-zero-by-2050
5. S. Evans, Renewables will cover almost all of global electricity demand growth out to 2025, becoming the world's top source of electricity within three years, new figures reveal, Carbon Brief, 08 February 2023. Available online: https://www.carbonbrief.org/renewables-will-be-worlds-top-electricity-source-within-three-years-iea-data-reveals//
6. International Energy Agency. World Energy Outlook, 2021.
7. A. Jäger-Waldau, Snapshot of Photovoltaics – February 2022, EPJ Photovoltaics **13**, 9 (2022)
8. IEA PVPS, Snapshot of Global PV Markets 2023, Report IEA-PVPS T1-**44**:2023, April 2023
9. I. Parry, S. Black, N. Vernon, Still Not Getting Energy Prices Right: A Global and Country Update of Fossil Fuel Subsidies, IMF working paper WP/21/236. Available from: https://www.imf.org/en/Publications/WP/Issues/2021/09/23/Still-Not-Getting-Energy-Prices-Right-A-Global-and-Country-Update-of-Fossil-Fuel-Subsidies-466004 **xx**
10. Bloomberg New Energy Finance, Energy Transition Investment Trends 2023, 23 January 2023
11. Market and Market, Concentrating Solar Power Market – Global Forecast to 2027. Available from: https://www.marketsandmarkets.com/Market-Reports/concentrating-solar-power-market-199506567.html
12. E. Pursiheimo, H. Holttinen, T. Koljonen, Renew. Energy **136**, 1119 (2019)
13. D. Bogdanov et al., Energy **227**, 120467 (2021)
14. J.C. Goldschmidt, L. Wagner, R. Pietzcker, L. Friedrich, Energy Environ. Sci. **14**, 5147 (2021)
15. D. Bogdanov, A. Gulagi, M. Fasihi, Ch. Breyer, Full energy sector transition towards 100% renewable energy supply: Integrating power, heat, transport and industry sectors including desalination, Appl. Energy **283**, 116273 (2021)
16. A. Jäger-Waldau, Snapshot of Photovoltaics – February 2018, EPJ Photovoltaics **9**, 6 (2018)
17. P. Mints, Statistics as I work on my annual shipment report (2022). Available from: https://www.linkedin.com/posts/paulamints_2022-statistics-as-i-work-on-my-annual-shipment-activity-7044044062328328192-Yqrt/?originalSubdomain=pf
18. Bloomberg New Energy Finance, Interactive Dataset, Equipment Manufacturers, last updated 29 March 2023
19. Ch. Breyer et al., Reflecting the energy transition from a European perspective and in the global context – Relevance of solar photovoltaics benchmarking two ambitious scenarios, Progr. Photovolt. Res. Appl. (2022). https://doi.org/10.1002/pip.3659
20. N.M. Haegel et al., Photovoltaics at multi-terawatt scale: waiting is not an option, Science **380**, 39 (2023)
21. Photovoltaics Report, Fraunhofer Institute for Solar Energy Systems, ISE (21 February 2023)
22. J. Götze, R. Möckel, Eds. *Quartz: Deposits, Mineralogy and Analytics* (Springer-Verlag, Berlin, Heidelberg, 2012)
23. Y. Zhang, M. Kim, L. Li Wang, P. Verlinden, B. Hallam, Design considerations for multi-terawatt scale manufacturing of existing and future photovoltaic technologies: challenges and opportunities related to silver, indium and bismuth consumption, Energy Environ. Sci. **14**, 5587 (2021)
24. G. Kavlak, J. McNerney, R.L. Jaffe, J.E. Trancik, Metal production requirements for rapid photovoltaics deployment, Energy Environ. Sci. **8**, 1651 (2015)
25. J. Jean, P.R. Brown, R.L. Jaffe, T. Buonassisi, V. Bulović, Pathways for solar photovoltaics. Energy Environ. Sci. **8**, 1200 (2015)
26. Bloomberg New Energy Finance, 1H 2022 LCOE update, 30 June 2022 (2022)
27. Bloomberg New Energy Finance, 2H 2022 LCOE update, 08 December 2022 (2022)
28. Bloomberg New Energy Finance, 2H 2022 Battery Metals Outlook: Short-Term Risks to Growth, 23 December 2022 (2022)
29. Bloomberg New Energy Finance, 1H 2023 Energy Storage Market Outlook, 20 March 2023 (2023)
30. E. Vartiainen, G. Masson, Ch. Breyer, D. Moser, E. Román Medina, Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity, Prog. Photovolt. Res. Appl. **28**, 439 (2019)
31. S. Szabo, A. Jäger-Waldau, More competition: threat or chance for financing renewable electricity? Energy Policy **36**, 1436 (2008)
32. TrendForce, New PV Installations Worldwide Will Grow by More Than 50% YoY to 351GW for 2023 Thanks to Rising Demand, Press release 16 February 2023. Available from: https://www.trendforce.com/presscenter/news/20230216-11568.html
33. Bloomberg New Energy Finance, 1Q 2023 Global PV Market Outlook, 28 February 2023 (2023)
34. International Energy Agency, Climate Risks to African Hydropower, June 2020 (2020). Available from: https://www.iea.org/reports/climate-impacts-on-african-hydropower/climate-risks-to-african-hydropower
35. R. Gonzalez Sanchez et al, Assessment of floating solar photovoltaics potential in existing hydropower reservoirs in Africa, Renew. Energy **169**, 687 (2021)
36. World Bank, Scaling Solar Programme. Available from https://www.scalingsolar.org/
37. P. Ferrera, "Dessert-to-Power": The Sahel seeks to harness the sun, Atalayar, 21 January 2021. Available from: https://atalayar.com/en/content/desert-power%E2%80%9D-sahel-seeks-harness-sun%C2%A0%C2%A0

38. New and Renewable Energy Authority (NREA), Benban 1.8 GW PV Solar Park, Egypt, Strategic Environmental & Social Assessment – Final report, February 2016. Available from: https://www.eib.org/attachments/registers/65771943.pdf
39. United States Congress, Inflation Reduction Act, Public Law 117–169—AUG. 16, 2022. Available from: https://www.govinfo.gov/content/pkg/PLAW-117publ169/pdf/PLAW-117publ169.pdf
40. Solarbe Global, Brazil to rise up as global major solar market, July 2022. Available from: https://www.solarbeglobal.com/brazil-to-rise-up-as-global-major-solar-market/
41. IEA PVPS, Country Report China 2022
42. European Commission, REPowerEU Communication, 08.03.2022, COM(2022) 108 final
43. European Commission, Solar Strategy Communication, 18.05.2022, COM(2022) 221 final
44. A. Chatzipanagi, A. Jäger-Waldau, The European Solar Communication – will it pave the road to achieve 1 TW of photovoltaic system capacity in the European Union by 2030? Sustainability **15**, 6531 (2023)
45. Greenpeace International, European Renewable Energy Council (EREC), Global Wind Energy Council (GWEC), Energy [r]evolution, 5th edition 2015 world energy scenario (2015). Available from: https://urldefense.com/v3/__https:/wayback.archive-it.org/9650/20200317060903/http:/*p3-raw.greenpeace.org/new-zealand/Global/international/publications/climate/2015/Energy-Revolution-2015-Full.pdf__;Lw!!DOxrgLBm!HwSSv28SKwjhNX-gTNn1-bzymUN1izwxQwdfwelpyUMhIgChVd6lw7D ho6BmkKvM5Jk4DZIpkbShrMHVu_JVyk6T3mXcNEs$
46. M. Ram et al., Global Energy System based on 100% Renewable Energy – Power Sector, (2017), Study by Lappeenranta University of Technology and Energy Watch Group, Lappeenranta, Berlin (2017)
47. M. Ram et al., Global energy system based on 100% renewable energy – power, heat, transport and desalination sectors, in *Study by Lappeenranta University of Technology and Energy Watch Group*, Lappeenranta, Berlin (2019)
48. Bloomberg New Energy Finance, New Energy Outlook 2020 (2020)
49. IRENA, Global Energy Transformation: A roadmap to 2050, 2019 edition (2019)
50. M. Marconcini et al., Outlining where humans live, the World Settlement Footprint 2015, Sci. Data **7**, 242 (2020)
51. P. Gagnon et al., Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment (NREL, 2016)
52. K. Bódis et al., A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union, Renew. Sustain. Energy Rev. **114**, 109309 (2019)
53. A. Jäger-Waldau, The untapped area potential for photovoltaic power in the European Union, Clean Technol. **2**, 440 (2020)
54. N. Lee et al., Hybrid floating solar photovoltaics-hydropower systems: Benefits and global assessment of technical potential, Renew. Energy **162**, 1415 (2020)
55. J. Farfan, Ch. Breyer, Combining floating solar photovoltaic power plants and hydropower reservoirs: a virtual battery of great global potential, Energy Procedia **155**, 403 (2018)
56. G. Kakoulaki et al., Benefits of pairing floating solar photovoltaic with hydropower reservoirs in Europe (National and Regional Level), Renew. Sustain. Energy Rev. **171**, 112989 (2023)
57. A. Chatzipanagi, N. Taylor, A. Jaeger-Waldau, Overview of the potential and challenges for Agri-Photovoltaics in the European Union, EUR 31482 EN, Publications Office of the European Union, Luxembourg (2023)
58. M. Pehl et al., Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modeling, Nat. Energy **2,** 939 (2017)

Cite this article as: Arnulf Jäger-Waldau, Snapshot of Photovoltaics – May 2023, EPJ Photovoltaics **14**, 23 (2023)