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Snapshot of photovoltaics – February 2022

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Abstract. For the past 10 years photovoltaic electricity generation has been the fastest-growing power generation source worldwide. It took almost six decades to achieve 100 GW of solar energy capacity in 2012, but the 1 TW level is likely to be broken during 2022. Overall investments in solar energy has increased by 19% to USD 205 billion (EUR 171 billion). In 2021 more than 180 GW of new solar photovoltaic electricity generation capacity was installed. After the decline in 2020, the Chinese solar market recovered to 53 GW in 2021. This development and the continuous growth in Europe and the USA as well as in new emerging markets were the main drivers. The number of countries installing more than 1 GW annually has increased to 18 in 2021. The continuation of price reductions in the battery storage sector has again resulted in a growing market for local battery storage systems in solar farms as well as for decentralised photovoltaic electricity generation systems. It is also increasingly clear that apart from classic electricity use, renewable electricity for electric vehicles and for generation of green hydrogen will become more and more important in the future.

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

1 Introduction

The 26th Conference of the Parties to the United Nations Framework on Climate Change (COP26) ended with the finalization of the Glasgow Climate Pact [1]. The Glasgow Pact reiterated the long-term goal to limit the global average temperature increase to "well below 2 °C" above pre-industrial levels and to continue the efforts to limit temperature increase to 1.5 °C. One of the conclusions of the pact is that limiting the global average temperature increase to 1.5 °C requires "rapid, deep, and sustained reductions in global greenhouse gas (GHG) emissions, including reducing global carbon dioxide emissions by 45 per cent by 2030 relative to the 2010 level and to net zero around mid-century, as well as deep reductions in other greenhouse gases".

Electrification of the world energy use and supply of this electricity by renewable and low GHG sources is one of the keys to achieve the target of the Glasgow Pact. The 2021 edition of the World Energy Outlook Report published by the International Energy Agency (IEA) stated that "Electricity's share of the world's final consumption of energy has risen steadily over recent decades, and now stands at 20%" [2]. According to the same report, electricity will represent around 50% of final energy use by 2050 in the net zero by 2050 scenario (NZE) [3], compared to about 30% in the "Announced Pledges Scenario". The increase in electrification will also increase the overall energy efficiency, if non-combustion renewable energy sources are used.

Of all the presented pathways 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. According to this scenario, he crucial timespan to achieve globally 40% greenhouse gas (GHG) emissions reduction by 2030 starts now. To achieve this goal, renewable sources must provide 61% of the global electricity generation, which is more than double the percentage in 2020 (28%), and rising in terms of total electricity generation, as the latter is projected to increase from 26 778 TWh in 2020 to 37 316 TWh in 2030. This scenario requires an increase in renewable electricity generation from 7 660 TWh to 22 817 Wh within the same timeframe.

NZE would need a substantial increase in clean energy investments. According to the IEA to achieve NZE the annual investment in clean energy would need to increase to USD 4 trillion by 2030, more than tripling from current levels. However, according to the IMF, this is only about two thirds of the USD 5.9 trillion what governments are spending globally every year to directly and indirectly subsidise fossil fuels [4]. This amount includes environmental costs and foregone consumption taxes.

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One of the key technology options, apt for scalability in a short period of time, is solar photovoltaics (PV), which can be deployed in a modular way almost everywhere on this planet. Solar resources across the world are abundant and cannot be monopolised by one country.

According to NZE, the worldwide installed PV capacity would need to increase to 4956 GW by 2030 (this is about 1000 GW higher compared to the IEA estimation published in 2020) and 14,458 GW by 2050. In such a scenario solar photovoltaic electricity would account for about 6970 TWh (19%) in 2030 and 23,469 TWh (33%) in 2050 of the worldwide electricity supply. However, even the "Net Zero Emissions by 2050" scenario still falls short compared to more ambitious scenarios, which call for 100% renewable electricity or even a 100% renewable energy supply by 2050 [5–7].

2 PV solar cell production

The global cell production[1] during 2021 was in the range of 190–201 GW; and is expected to increase by 20–30% in 2022. 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 [8].

The data presented, collected from stock market reports of listed companies, market reports and colleagues, were then compared to various data sources, which led to an estimate of 202.6 GW (Fig. 1), representing an increase of over 37% compared to 2020.

Over the past decade, solar system hardware has seen a steep price decline, which, coupled with fierce competition amongst the manufacturing companies along the solar value chain, resulted in an ongoing consolidation in the solar industry. In December 2021, Bloomberg New Energy Finance reported that they tracked more than 700 companies along the crystalline silicon value chain i.e. polysilicon, wafer, solar cells and module manufacturing [9]. The combined manufacturing capacity of the over 260 silicon solar cell plants was 338.4 GW. This is an increase in capacity of 235% compared to the 144 GW capacity at the end of 2017. An additional 72.4 GW are under construction and 165 GW announced.

Due to the plant complexity and technological challenges, polysilicon and wafer factories have the highest investment costs as well as the longest construction time. Therefore, the consolidation in these two value chain segments is the highest. On the other hand, new factories are more competitive due to lower production costs. Solar cell and module manufacturing plants are more modular and can be built faster, thus offering more flexibility to react to technology progress or impacts of policy decisions, like local content rules and import tariffs.

In order to realise any of the various scenarios to limit global warming to 1.5 °C, as pledged in the Paris Agreement, the scale-up of renewable energy deployment and acceleration of the energy system decarbonisation over the next decade is crucial. The annual increase in manufacturing output required depends on the ambition of the scenario. An increase of the annual solar module production from about 190 GW in 2021 to about 820 GW would be necessary for the NEZ WEO 2021 scenario or above 2.5 TW for a 100% renewable energy scenario. This huge challenge raises the question of whether PV technology and the industry are ready for it.

In the past decade, the global production of the solar photovoltaic manufacturing industry has increased from 21 GW in 2010 to about 202 GW in 2021 with a compound annual growth rate (CAGR) of 25%. A continuation of this trend, which is technologically feasible, would lead to an annual production of 1.45 TW in 2030 [10,11]. To reach the 100% renewable energy benchmark of 2.5 TW annual production, the CAGR would have to increase to 33%. Such an increase could be realised without major problems, if PV manufacturing growth is not only driven by Asian countries, but if major economic powers like Europe and the USA would increase their share of currently less than 1% of solar cell production to a level to supply at least 25 to 30% of their local markets.

Various studies whether or not the solar photovoltaic industry can be scaled to the meet these production targets concluded that raw material availability is not a real issue that limits the growth of PV manufacturing. For some thin film technologies, production volumes could be limited [12,13]. This is not the case for silicon solar cells, which account for 95% of the current market [14], as silicon is one of the most abundant materials on Earth. Silver, Indium and bismuth, which are used as contact materials are often cited as a limiting factors. Research and technology development is needed and under way to reduce the amount of material used per Wp [15]. In addition, technology progress in terms of efficiency increases and alternative contact materials as well as circular manufacturing concepts in various industries will enable the required grow of the PV industry.

3 Solar PV electricity generation and markets

Over the past few years, the CAPEX for PV solar systems have converged globally. However, differences in market size and local competition can still lead to significant variations. Factors like import taxes, local content rules or existing tax credits have an additional influence on local prices. A global benchmark for the levelised cost of electricity (LCOE) is published regularly by Bloomberg New Energy Finance (BNEF) [16]. In the 2nd half (H2) of 2021, this benchmark for utility scale PV systems was USD 43 per MWh for non-tracking and USD 40 per MWh for tracking systems. It should be noted that, due to the

[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.

Table 1. World-wide scenarios of cumulative solar photovoltaic electrical capacities until 2040.

Year	2021 [GW]	2025 [GW]	2030 [GW]	2040 [GW]
Actual Installations	**953**			
Greenpeace (advanced [r]evolution scenario)		2000	3725	6678
LUT 100% RES Power 2017		3513	6980	13 805
LUT 100% Energy 2019		1628	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 2021**		1365	2550	4516
IEA Sustainable Development Scenario** 2021		1630	3582	7421
IEA NZE Scenario** 2021		1916	4956	10 980

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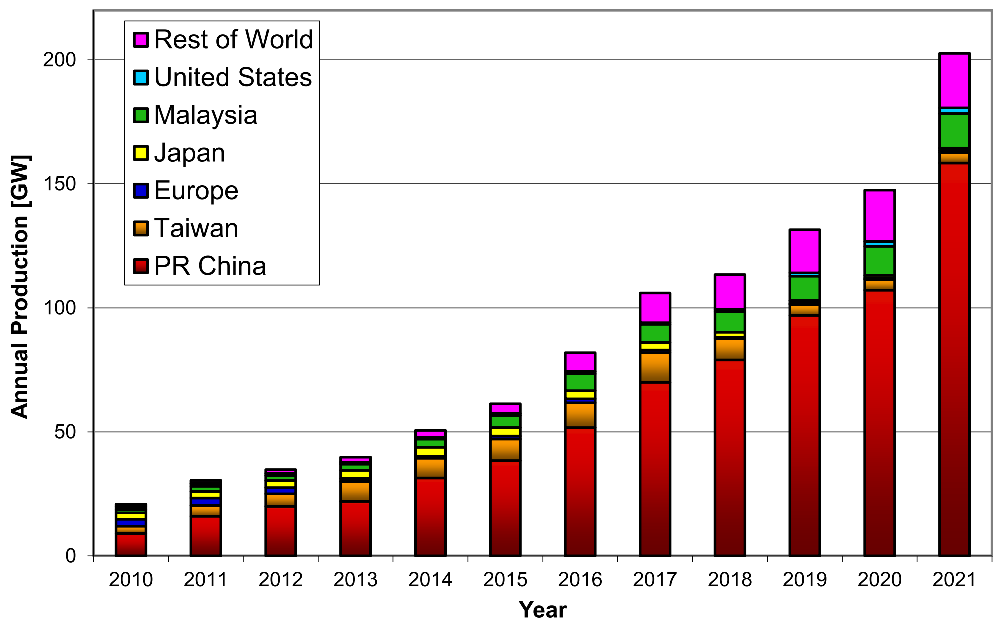

Fig. 1. World PV cell/thin film module production from 2010 to 2021.

module price increase in the second half of 2021, these LCOE values are about 10% higher than in the first half of 2021. The main drivers for the module price increase were the polysilicon price increase by over 350% and the increase of freight rates by over 470%. Nevertheless, solar LCOE was more than 30% lower than the LCOE for coal and gas without carbon capture and sequestration (CCS) and 85% lower if CCS would be used.

In the last decade, lithium-ion battery packs have exhibited a learning rate of 18% and a price decrease of 89%. The corresponding levelised cost of electricity storage (LCOES) for battery systems ranges between USD 120 and 143 per MWh for a 4-hour storage system and between USD 167 and 193 per MWh for a 1-hour storage system. The short time (1 h) battery storage systems are most suited to provide balancing services as well as capacity. Their role can be compared to peaker plants with open-cycle gas turbines, which run infrequently for a maximum of 1 h per day. On the other hand a 4-hour storage runs on a daily cycle providing electricity during times when the PV system is not generating. There are indications that the LCOES can be even lower with a 6h storage system [17].

In the last years, the number of residential and commercial PV projects with storage has increased substantially, driven by this price development, various government incentive programmes and rising electricity prices during peak demand hours. The addition of storage in large scale PV systems is driven by factors like the increase of the AC connection utilisation, access to new market segments at times without solar radiation and

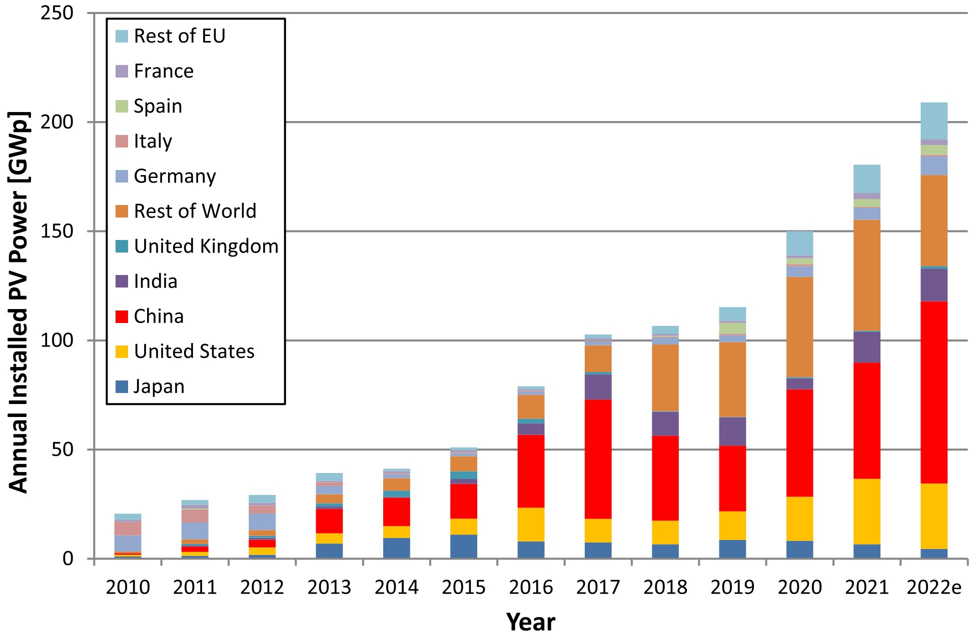

Fig. 2. Annual photovoltaic installations from 2010 to 2021 with estimates for 2022 (data source: [25–28] and own analysis).

guarantee of power quality during ramp times. According to industry analysts, about 10–12 GW (25–28 GWh) of new energy storage capacity will have been added in 2021 [18,19]. A growth of up to 50% is predicted for 2022.

Compared to the benchmark LCOE mentioned earlier, local electricity generation costs with photovoltaic systems are determined by a number of additional 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. It is important to remember that one of the most relevant factors is the financing of a project [20]. The share between debt and equity as well as interest rates and return on equity expectations has great influence and can differ substantially from country to country. For this reason, solar energy investors seek stable environments that provide certainty over the long term. The ability to participate in the electricity market is another factor that influences installation and financing costs and thus the competitiveness of renewable energy investments [21].

During 2021, the second year of the ongoing COVID-19 pandemic, global investments in renewable energy increased by 12% to USD 417 billion [22]. Investments into new solar capacity increased by 19%, reaching USD 205 billion. Preliminary data show that the new PV capacity increased by about 15% to over 180 GW in 2021 (Fig. 2), which is in the middle of the conservative and optimistic forecasts [23,24]. For 2022, market forecasts are considerably higher, with an annual new installed capacity above 200 GW, which would bring the total cumulative installed PV capacity to about 1.2 TW (Fig. 3).

China currently has a cumulative installed capacity of more than 300 GW, representing roughly one third of the total global 965 GW installed PV capacity. The European Union follows with about 17% or 166 GW and the USA with over 125 GW (Fig. 3).

Africa: During the past decade, the total installed solar PV capacity has increased by two orders of magnitude from about 110 MW in 2010 to over 15 GW at the end of 2021. Already 15 African Nations are home to more than a 100 MW of PV capacity. Egypt and South Africa are still the countries with the highest installed capacities and they account for roughly 49% of the total capacity. The continent has vast solar resources but hydropower is still the largest source of renewable electricity generation, with hydro dams supplying 17% of the demand. However, water scarcity and climate change could hamper future expansion. Floating PV could be a potential alternative to expand the electricity generation of hydro dam plants. Covering just 1% of the total surface of existing reservoirs could increase the total annual electricity output of these plants by 50% [29].

An important tool to finance large solar PV projects in Africa is the World Bank's Scaling Solar programme [30]. So far, seven African Nations, Côte d'Ivoire, Ethiopia, Madagascar, Niger, Senegal, Togo and Zambia have signed financing agreements.

In 2018 the Africa Development Bank (AfDB) launched an initiative called "Desert to Power", which aims to deploy 10 GW solar power for the 250 million people across the Sahel zone. On 16 September 2019, on the occasion of the G5 Sahel summit in Ouagadougou, the heads of state gave strong support to this initiative. In December 2020, the AfDB released the first grants with a value of USD

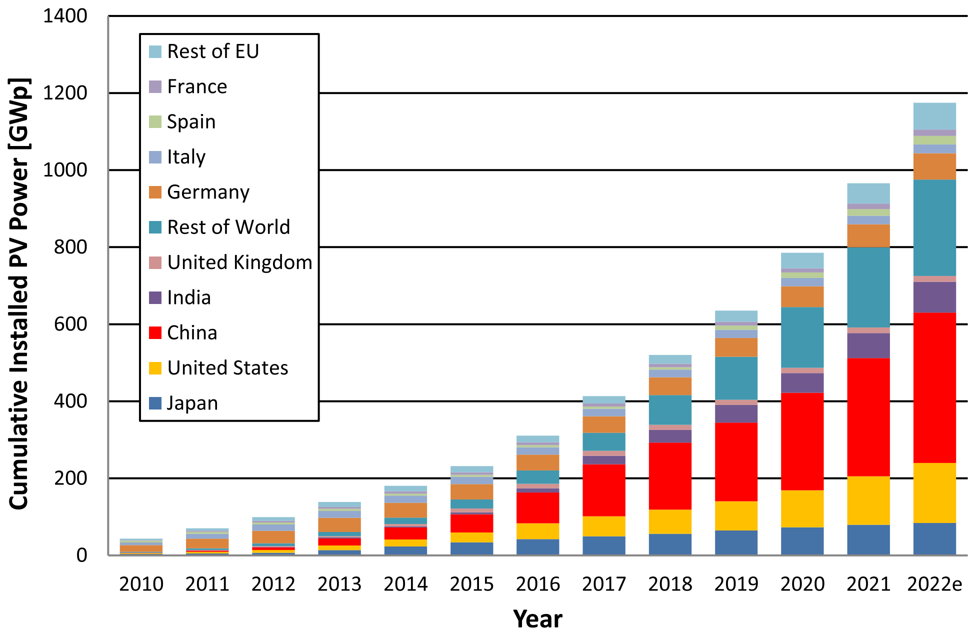

Fig. 3. Cumulative Photovoltaic Installations from 2010 to 2021 with estimate for 2022 (data source: [25–28] and own analysis).

6.5 million for projects in Chad, Burkina Faso, Niger, Mauritania and Mali through the Sustainable Energy Fund for Sustainable Africa (SEFA) [31].

With 2 GW_{AC} power, the Benban solar complex is currently the largest solar project in Africa, located near Aswan in upper Egypt. The Benban project consists of 41 individual plants, of which 31 have a 50 MW_{AC} (64 MW_{DC}) capacity each, whereas the remaining 10 projects have different capacities, due to the shape of the area [32].

Americas: Following a growth of more than 32% in the combined North and South American markets, new solar photovoltaic power capacity of about 41 GW was added in 2021. The three largest markets in 2021 were the USA (over 25 GW) Brazil (6 GW) and Chile (1.8 GW). Currently, the Americas have an overall installed capacity of 120 GW, of which about 75% is in the USA alone. For 2021, market forecasts indicate the possibility of adding more than 50 GW.

In 2020 the federal Investment Tax Credit (ITC) in the USA was extended until 2023 a possible extension until 2026 would support growth in the PV market for the coming years. It should be noted that a growing number of US States have tax credits as well, which can be added to the federal ITC.

According to IHS Markit, more than 16 GW of PV capacity is expected to be added across Latin America in 2022 [33]. Close to 60% of this capacity is expected to be installed in Brazil alone. Chile will follow with about 16%.

Asia & Pacific Region: In 2021, China installed more than 53 GW of new solar photovoltaic power generation capacity, according to the Chinese National Energy Administration [34]. After a declining PV market in 2020, India recovered and added about 14 GW of new solar photovoltaic installations. A support scheme by the Ministry of New and Renewable Energy (MNRE) for residential PV systems aims to install up to 4 GW until the end of next year. Stable markets in Australia, Israel, Japan, South Korea and Vietnam supported the Asian-Pacific PV market to grow by 10% to 94 GW. For 2022, a growth of up to 25% is possible, which would lift the annual market above the 100 GW level.

European Union: Two years after approving a major policy package on climate and energy, in December 2020 the European Council endorsed a new binding EU target for a net domestic reduction in greenhouse gas emissions of at least 55% by 2030, compared to 1990 levels. This is 15 percentage points higher than the previous 2030 target, which had been agreed just in 2018. The 55% GHG reductions target will require a share of renewable energy of around 38.5%, according to the impact assessment, including the installation of additional PV capacities between 325 and 375 GW in the timeframe 2020 to 2030 [35]. Thus, to achieve this goal, the PV market volume in the EU would have to grow between three and five times compared to 2020 levels. However, these numbers could double if the electricity demand rises faster than what current projections indicate [36].

At the end of May 2021, the European Council received the formal notification about the approval of the Recovery and Resilience Facility by all Member States. Together with the next long term budget this represents EUR 2.02 trillion (USD 2.46 trillion) of spending between 2020 and 2027 [37].

Preliminary data show that the annual market continued with more than 25% growth in the European Union to about 25–26 GW in 2021. Seven countries installed more than 1GW, namely Germany (5.2–5.4 GW), Spain (3.6–3.8 GW), the Netherlands (3.2–3.4 GW), Poland (3.1–3.3 GW), France (2.6–2.8 GW), Greece (1.4–1.6 GW) and Denmark (1.1–1.3 GW). EU countries with previously moderate PV instalment rates became hotspots in last 2 years for rapid PV development like Sweden, Hungary and Portugal.

4 Conclusions

Solar photovoltaic electricity generation is already the lowest cost generation source in many countries and the number where this holds true is continuously growing. The photovoltaic electricity generation technology still has a significant potential for further cost reduction. For dispatchable power supply just solar PV combined with storage already now offer the most economic solution in many cases. These facts will drive the further rapid growth of PV installations in the coming decades. 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 [2,38–42]. References to earlier scenarios can be found in last year's report [43].

All scenarios show vast growth potentials for PV power in the future, regardless of the existing differences in the deployment pathways and ambitions. To supply the 2020 global electricity generation of 26 907 TWh with solar PV would require about 19 500 GW of PV capacity and approximately 0.3% of the world's land area. Various studies have shown that vast unused generation potentials exist on rooftops, facades, dual use of infrastructure, brownfield or novel applications like agri-photovoltaics or floating PV systems [29,44–48].

Key to all is an enabling policy framework and the support of all stakeholders. Fundamental system change is needed for the energy transition, including the massive deployment of solar, but this will not happen by itself. To stay on track for a maximum of 1.5 °C global temperature increase, our societies have to acknowledge the need of an accelerated energy transition towards a net zero carbon energy supply by 2050. Solar photovoltaics is a crucial pillar to achieve this due its very low (based on a full life cycle analysis) CO_2 footprint, its modularity, and its "no emission no pollution" characteristics make it a perfect solution for a dense urban environment [49]. The number of barriers ranging from perception, legal and regulatory conditions as well as technical limitations of the existing transmission and distribution systems is still high. So far, neither the political will to accelerate the use of renewable energy sources such as PV nor the necessary adaptation and transformation of the energy networks is in line with the urgent need 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.

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