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Editorial Article

Exploring the Rapid Growth of Solar Photovoltaics in the European Union

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1. Introduction

The solar irradiance emanating from the Sun consistently bestows an average energy influx of approximately 1.73 x 10^{17}joules per second upon the terrestrial sphere. As depicted in Figure 1, the annual mean radiation intensity experienced across the Earth's surface exhibits a range spanning from approximately 100 to 250 watts per square meter, a variability attributed to geographical latitude disparities and climatic conditions. Over the course of a year, the cumulative solar energy intercepted by the Earth surmounts to nearly four million exajoules (1 EJ = 10^{18}J). From this total, an estimated quantity of approximately 5 x 10^4 EJ appears readily exploitable. This magnitude significantly surpasses both extant and anticipated human primary energy requisites, which were gauged to be approximately 533 EJ in 2010 and are projected to escalate to 782 EJ by 2035, predicated upon prevailing policy frameworks [1-5].

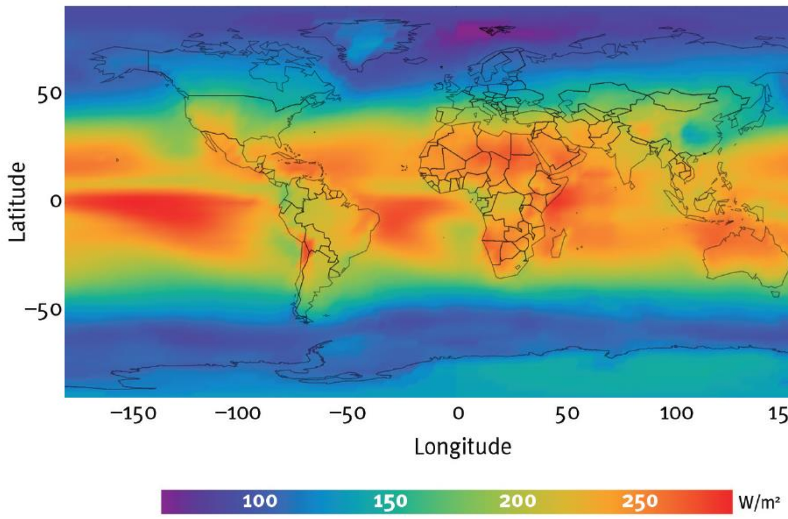

Figure 1. The distribution of the yearly average solar irradiation across the Earth's surface.

Notwithstanding the considerable capacity inherent in solar energy, a mere 0.3% of the global primary energy demand and 0.5% of the global electricity demand are presently satisfied by solar power. Anticipated trajectories toward low-carbon development posit that by the year 2050, a range from 14% to 22% or potentially more of electric power generation should derive from solar conversion. Within these envisaged pathways, solar energy, alongside other low-carbon technologies, assumes a pivotal role in effecting the decarbonization of the power sector [6,7].

The amount of renewable energy capacity globally is projected to increase by 107 gigawatts in 2023, reaching over 440 GW, the highest absolute growth on record. The magnitude of this increase surpasses the collective installed power capacity of Germany and Spain, signaling a substantial milestone in renewable energy expansion. Such unprecedented growth is underpinned by the proliferation of policy initiatives endorsing renewable energy sources, mounting apprehensions regarding energy security, and an escalating competitive edge against traditional fossil fuel counterparts. These influential drivers overshadow the concomitant challenges of escalating interest rates, augmented investment outlays, and enduring complexities within the supply chain network [8-11].

In the fiscal year of 2022, worldwide fresh capital infusion into renewable power and fuels ascended to an unprecedented pinnacle, reaching a commendable sum of USD 495.4 billion. Nevertheless, this allocation represented a mere fraction, constituting approximately 29.4%, of the comprehensive global investment disseminated across the domains of power, fuel supply, and associated infrastructure, as delineated in Figure 2. Noteworthy augmentation, equating to 17.2%, was discerned in investments directed towards renewable power and fuels from the preceding year, predominantly attributable to the marked proliferation of solar PV installations on a global scale [12].

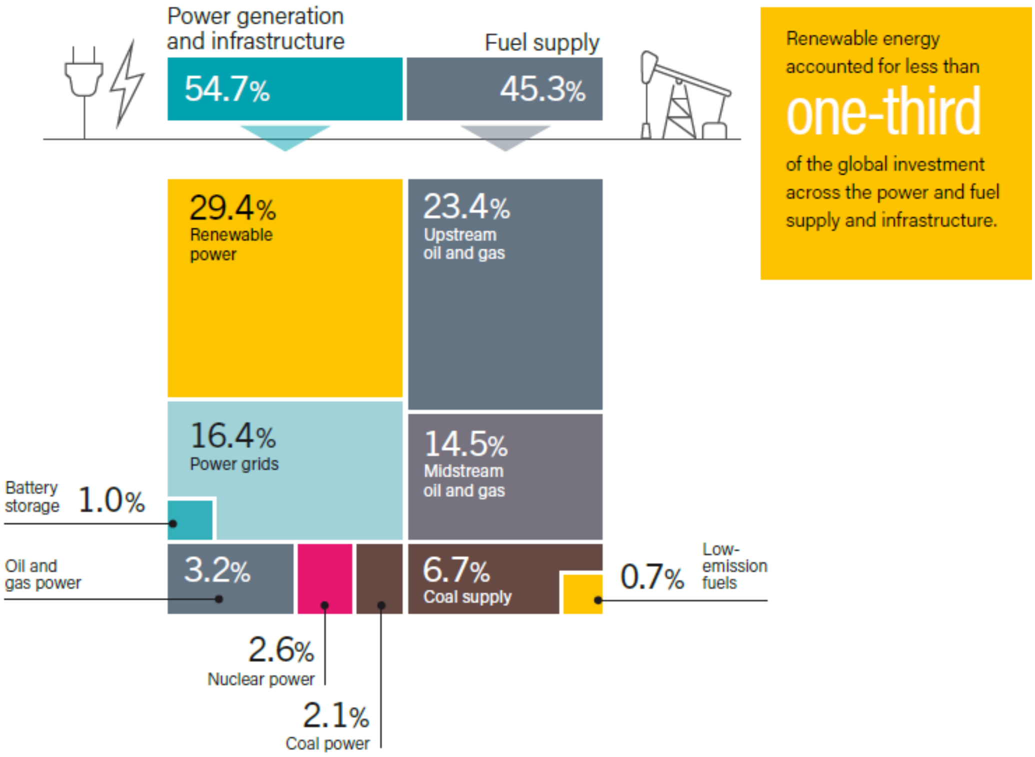

Figure 2. Global Investment in the Energy Sector for the year 2022 [13].

Solar PV capacity, encompassing both expansive utility-scale installations and compact distributed systems, constitutes a significant proportion of the anticipated augmentation in worldwide renewable energy capacity for the current year. In light of escalated electricity costs stemming from the prevailing global energy predicament, governmental authorities across numerous nations, notably in Europe, have proactively pursued substitutes to externally sourced fossil fuels with the aim of enhancing energy resilience. This transition in emphasis has engendered a conducive milieu for solar PV technologies, particularly in the domain of residential and commercial applications, which can be swiftly deployed to cater to the escalating requisites for sustainable energy sources.

After experiencing two consecutive years of contraction, the augmentations in onshore wind capacity are poised for a notable resurgence, forecasting a 70% increase to 107 gigawatts (GW) in 2023, marking an unprecedented pinnacle. This resurgence predominantly stems from the activation of projects in China that were previously delayed amid the Covid-19 restrictions imposed last year. Moreover, accelerated expansion is anticipated in both Europe and the United States, attributable to logistical hurdles within the supply chain, which have necessitated the postponement of project commissioning from 2022 to 2023 [14].

In the forthcoming year of 2024, the trajectory of solar photovoltaic (PV) additions is projected to sustain its upward trend, notwithstanding lingering impediments for wind energy expansion. Factors such as diminishing module prices, heightened adoption rates of distributed solar PV systems, and a concerted policy impetus towards large-scale deployment collectively contribute to the escalation in annual solar additions across major global markets, encompassing China, the European Union, the United States, and India [14]. Conversely, the outlook for global onshore wind additions in 2024 appears less favorable, with an anticipated decline of approximately 5% compared to 2023 levels in the absence of prompt policy interventions.

Although China's wind energy augmentations are anticipated to persist in their upward trajectory, these gains are expected to be counterbalanced by instances of undersubscription in auctions and impending delays in permitting procedures in Europe. However, the outlook for Europe is poised for amelioration with the envisaged implementation of new legislative measures. In aggregate, the cumulative global renewable capacity is forecasted to exceed 4,500 gigawatts (GW) by the conclusion of 2024, commensurate with the total power capacity of both China and the United States combined. In an accelerated scenario, the projections indicate that global renewable capacity additions have the potential to surge to 550 gigawatts (GW) by the year 2024, representing an approximate 20% increment compared to the primary forecast. This augmented capacity is primarily attributed to the expedited deployment of residential and commercial PV installations, predicated on the assumption of swifter execution of contemporary policies and incentivizing measures [15-19].

The implementation of policy initiatives across various European nations has necessitated a revision of our projections regarding renewable capacity additions within the European Union (EU) for the years 2023 and 2024, resulting in an upward adjustment by 40% compared to pre-existing estimates. The notable surge in distributed solar PV installations emerges as the primary catalyst behind this more optimistic outlook, contributing to nearly three-quarters of the total forecast revisions for the EU. This phenomenon is propelled by heightened electricity prices, rendering solar PV installations financially more appealing, alongside the augmentation of policy support within pivotal EU markets, particularly evident in Germany, Italy, and the Netherlands. Figure 3 demonstrates the reduction in cumulative power prices resulting from the addition of solar PV and wind energy sources, compared to the average European Union wholesale spot electricity price. The data is presented for both actual and no-renewable energy source (RES) additions scenarios from 2021 to 2023 [20].

During the period spanning from 2021 to 2023, consumers of electricity within the European Union (EU) are anticipated to realize substantial savings amounting to an estimated EUR 100 billion, courtesy of the integration of newly established solar PV and wind capacities. The expedited deployment of renewable energy resources across Europe since 2021 has served to alleviate the economic ramifications stemming from the energy crisis. The proliferation of cost-effective wind and solar PV technologies is projected to displace approximately 230 terawatt-hours (TWh) of costly fossil fuel-based electricity generation over the aforementioned timeframe, thereby contributing to the reduction of wholesale electricity prices across all European markets [20-23]. Absent these capacity expansions, the average wholesale price of electricity within the EU for the year 2022 would have been subject to an approximate 8% escalation, thereby adversely affecting consumers, enterprises, and governmental fiscal frameworks.

In this context, renewable energy sources have the potential to facilitate Europe in further reducing its reliance on natural gas for heating buildings in the upcoming winter season. The preceding year witnessed the second warmest winter on record across Europe, thereby contributing to a diminished demand for natural gas in building heating applications within the European Union (EU). During the period spanning from August 8th to August 14th, 2022, the hourly electricity generation originating from hard coal and natural gas, along with that derived from solar PV and wind sources, as well as the corresponding hourly wholesale electricity spot prices, is illustrated in Figure 4.

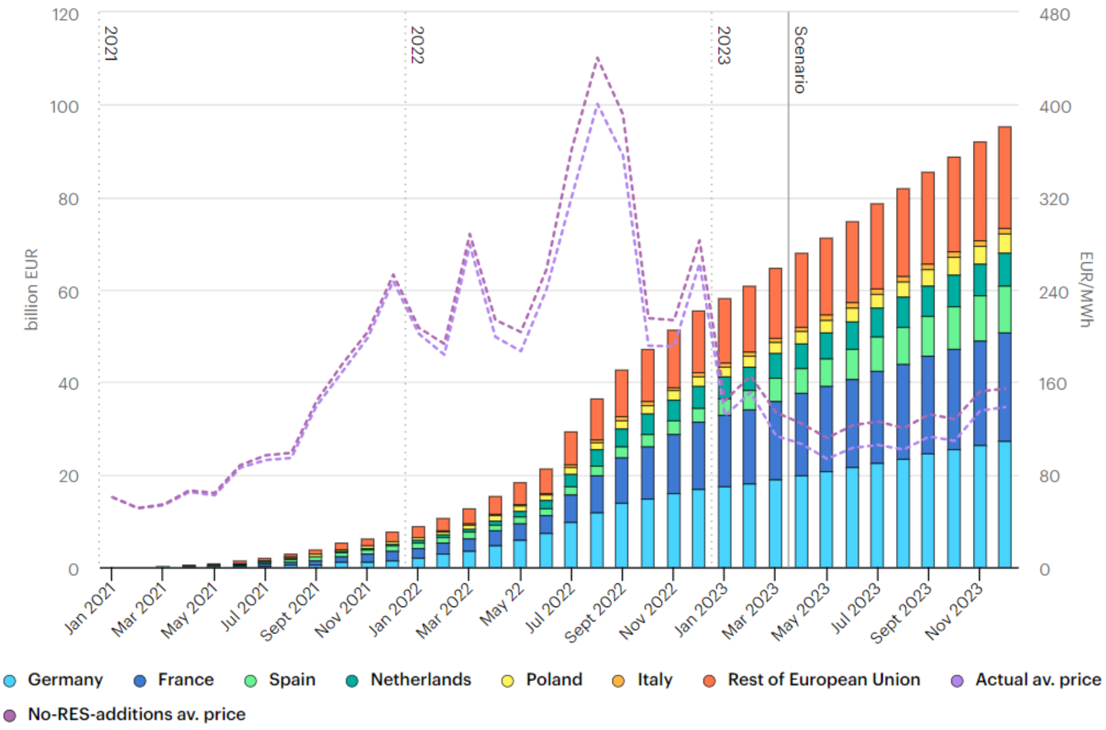

Figure 3. The reduction in cumulative power prices resulting from the addition of solar PV and wind energy sources, compared to the average European Union wholesale spot electricity price [20].

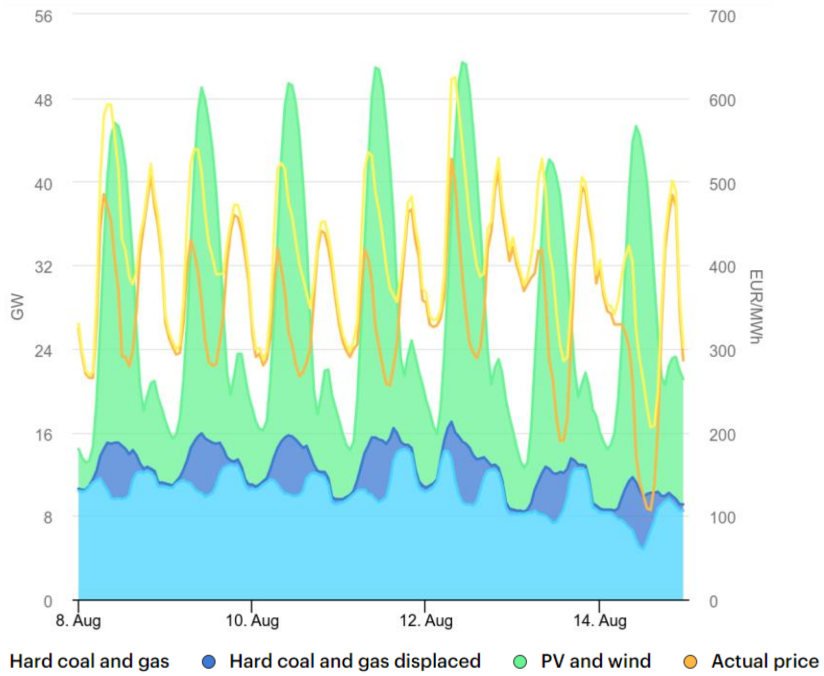

Figure 4. The hourly electricity generation originating from hard coal and natural gas, along with that derived from solar PV and wind sources, as well as the corresponding hourly wholesale electricity spot prices.

The swift proliferation of renewable energy technologies within building infrastructure holds the potential to alleviate the demand for natural gas within the European Union (EU) and concurrently bolster the bloc's energy security in the immediate future. Projections indicate that cumulative advancements in the direct utilization of renewable heat, coupled with the expansion of renewable electricity deployment beyond the year 2022, are poised to substantially mitigate EU buildings-related gas consumption [24, 25]. Specifically, it is estimated that nearly 8 billion cubic meters (bcm) of annual gas consumption in EU buildings could be displaced in 2023, with this figure escalating to over 17 bcm in 2024. This displacement corresponds to a reduction in carbon dioxide emissions exceeding 50 million metric tons (Mt) over the period spanning from 2023 to 2024.

The integration of solar photovoltaic (PV) systems into the grid utility infrastructure of the European Union (EU) presents significant implications for power quality. Harnessing artificial intelligence (AI), energy storage systems (ESS), and electric vehicles (EVs) collectively offers a multifaceted approach to addressing these effects while optimizing grid operations [26-33]. In this context, AI-driven predictive analytics can enhance the management of solar PV output variability by leveraging real-time data on weather patterns, solar irradiance levels, and grid demand. AI algorithms can forecast solar PV generation with greater accuracy, enabling proactive grid management to mitigate voltage fluctuations and frequency deviations.

Additionally, AI-powered control systems can optimize the operation of energy storage units, dynamically adjusting charging and discharging schedules based on solar PV generation forecasts and grid conditions to maintain grid stability and enhance power quality [34-43]. Moreover, energy storage systems play a pivotal role in smoothing out fluctuations in solar PV generation and providing grid ancillary services. By storing excess solar energy during periods of high generation and discharging it during peak demand or low solar output, ESS can stabilize grid frequency and voltage, mitigating power quality issues. Furthermore, ESS can support the integration of EV charging infrastructure by providing fast-charging capabilities and grid-to-vehicle (G2V) and vehicle-to-grid (V2G) services, thereby optimizing EV charging schedules to align with solar PV generation patterns and grid constraints [44-51]. In conclusion, the synergistic integration of solar PV, AI, ESS, and EVs presents a holistic approach to address power quality challenges in the EU grid utility. By leveraging AI-driven optimization, energy storage technologies, and electric vehicle integration, the EU can effectively manage solar PV variability, enhance grid stability, and ensure reliable, high-quality electricity supply while advancing towards a sustainable and resilient energy future.

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