Global photovoltaic potential in climate change scenarios: role of aerosols and associated costs

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Objective and background

Solar photovoltaic (PV) energy production has increased rapidly in the last decade, reaching 1TW of cumulative installed capacity in 2022. Future PV expansion is expected following improved policies to achieve climate goals, but at the same time, PV energy is modulated by climate. The aim of this study is to examine the future PV potential using the latest generation of climate projections, focusing on the role of atmospheric aerosols, and to estimate the climate-associated costs, that is currently lacking.

Methods

We use a multi-model ensemble of 11 global climate models (GCM) from the World Climate Research Programme's Coupled Model Intercomparison Project Phase-6 (CMIP6) to compare the historical experiment (1980-2010) with four climate change scenarios (2030-2100), ranging from SSP126 “low-emissions/green-growth” to SSP585 “high-emissions/fossil-fueled” hypothetical pathways. Climate projections are inputs in a resource-to-power conversion model to analyze the performance of two PV technologies with different temperature coefficients: thin-film and poly/mono-crystalline silicon modules. We test the statistical-significance of the climate/power changes and estimate the climate-associated costs for future solar farms with the Levelized Cost of Energy (LCOE).

Results and discussion

Results show significant increases in the PV potential in Europe, eastern America, and south Asia, while reductions predominate in the rest of the world due to decreased radiation (or non-significant changes) and increasing temperatures. The strong regional variability of the future solar resources is not only modulated by changes in cloud cover, but by atmospheric aerosols as well. In east Asia, increased PV potential is expected in all the scenarios except in SSP370, where increased aerosols could reduce the usable radiation. Hence, measures to reduce air pollution will not only mitigate harmful health impacts to the population but could also benefit the solar energy industry.

Increasing temperatures also affect the PV production, particularly poly/mono-Si modules. Research focused on improving the PV modules’ performance at high temperatures will improve their resilience to climate change. The climate impacts on future PV energy are lower in an “optimistic” scenario, SSP126, that simulates a development path compatible with the Paris Agreement’s 2°C target. Contrarily, the climate impacts on PV are the highest in the “pessimistic” SSP370 and SSP585 scenarios. Even in the more optimistic scenario, economic impacts could still be considerable in future large-scale solar plants, as shown in Figure 1. Among the plants considered, the 5GW Dholera Solar Park in India could face the highest impacts, with more than 60 million USD additional costs in one-year operation (1.8 billion USD in its lifetime) in the SSP126 scenario, and 140 million USD (4.2 billion USD in its lifetime) in the SSP370 scenario. Understanding future changes in the climate system will assist in long-term energy planning, choice of optimal project sites, and accurately estimating their reliability.

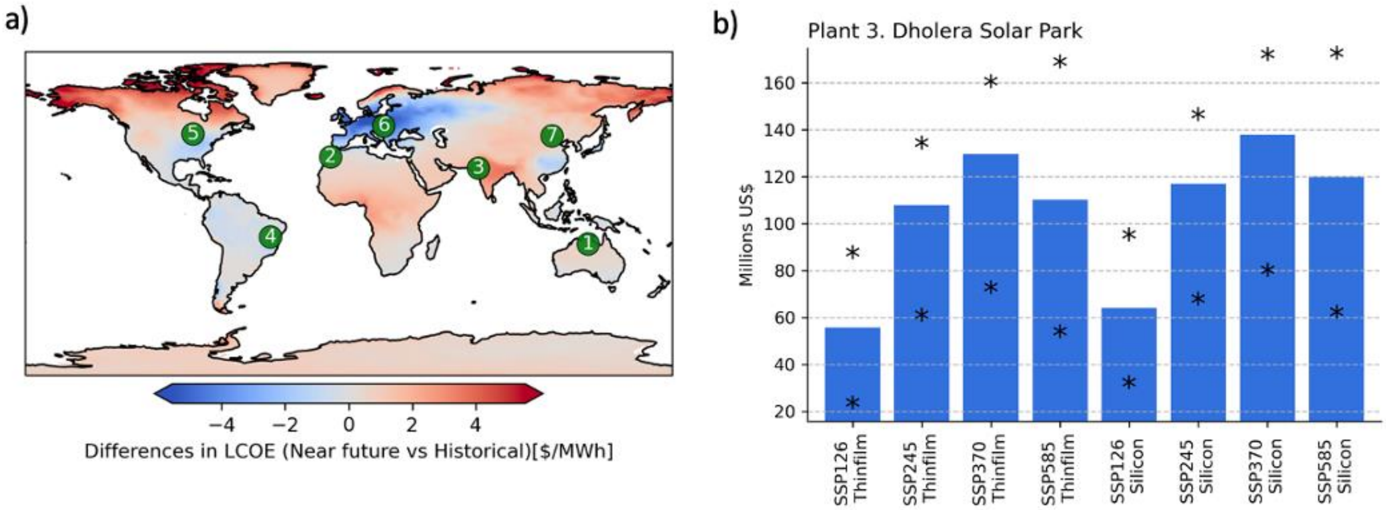

Figure 1. a) LCOE changes in SSP585 scenario in the near future (2030-2060) vs historical, for poly/mono-Si modules. b) Differences in the costs of one-year operation of Dholera Solar Park, considering different climates and PV technologies (Bars: multi-model mean, asterisks: percentiles 10 and 90 among the GCM).