Impact of Climate Change on Solar PV power potential in the Eastern Mediterranean and Middle East

Summary

In this study, we assess the impact of Climate Change on Photovoltaic (PV) energy production in the Eastern Mediterranean and Middle East (EMME) region. More specifically, we analyze projections from the GFDL-ESM4 global climate model, participating in the 6th phase of the Coupled Model Intercomparison Project (CMIP6). We investigate the future variability of solar irradiance, as well as atmospheric parameters affecting radiative transfer, under different Shared Socioeconomic Pathway (SSP)-based scenarios, namely SSP2-4.5, SSP3-7.0, and SSP5-8.5. Furthermore, we estimate the expected PV energy production using the climate data interface of the Global Solar Energy Estimator (GSEE).

Keywords: solar irradiance, solar energy, aerosols, clouds, photovoltaics, solar energy modelling

Field of application for the findings: Energy Meteorology

Addressed audience: Researchers and Engineers

1. Introduction

The Eastern Mediterranean and Middle East (EMME) region has been identified as a climate hotspot by several studies (e.g., Zittis et al., 2022). At the same time, the EMME region is characterized by consistently high solar resource availability (Fountoulakis et al., 2021). Assessing solar resources is essential for strategic planning for future installations, guiding investment decisions and minimizing financial risk, identifying optimal project locations, and shaping long term energy policies. In this context, PV modelling serves as a valuable tool, extending single solar resource assessments to estimates of actual PV energy production.

2. Data and Methodology

2.1 Climate Data

The analysis was conducted using projections from the GFDL-ESM4 Global Climate Model (GCM), participating in CMIP6, with monthly temporal resolution. The GFDL-ESM4 (Dunne et al., 2020) model provides detailed representation of various aerosol species We investigated the variability of the following variables: Surface Downwelling Shortwave Radiation (rsds), the Surface Downwelling Clear-Sky Shortwave Radiation (rsdscs), as well as the aerosol optical thickness. To assess future changes, we compared projections for a future period (2080–2100) against a historical reference period (1980–2000), focusing on the differences between the two periods (future minus past). The future projections are based on the SSP-based scenario framework of CMIP6 and were evaluated under three different SSPs: one medium forcing scenario (SSP2-4.5) and two high forcing scenarios (SSP3-7.0 and SSP5-8.5).

2.2 Solar PV power modelling

We simulated the electric output from PV systems using the Global Solar Energy Estimator (GSEE; Pfenninger and Staffel, 2016). GSEE is a library designed for rapid solar energy calculations. The user defines the characteristics of a complete PV system, including technology, capacity, tracking, tilt angle, orientation, and surface albedo at the installation site. Moreover, GSEE version 0.3.1 includes a climate data interface submodule that enables the processing of input solar radiation and temperature datasets with varying temporal resolutions, ranging from hourly to annual.

2.3 Cloud Modification Factor (CMF) approach

The influence of cloudiness is represented through the Cloud Modification Factor (CMF), defined as the ratio of all-sky to clear-sky GHI.

$$CMF = \frac{G_{all-sky}}{G_{clear-sky}} \qquad \text{(eq. 1)}$$

CMF is an indicative measure of the influence of cloudiness on down-welling solar irradiance, with values ranging from 1 under cloud-free conditions to lower values under increasing cloudiness, while in rare cases with scattered clouds, CMF may slightly exceed 1. On the other hand, cloud fraction provided by climate models is not sufficient to represent the impact of clouds on solar irradiance, as this would require more detailed information on cloud type and the distribution of clouds across the sky dome.

3. Results and Discussion

3.1. Solar Resource Assessment

The variability of surface downwelling shortwave radiation (rsds) is presented in Figure 1. A decrease is observed over the Middle East, while an increase is evident in the Eastern Mediterranean. This difference may be associated with the direct and indirect effects of atmospheric aerosols, which will be analyzed in more detail in the extended version of this work.

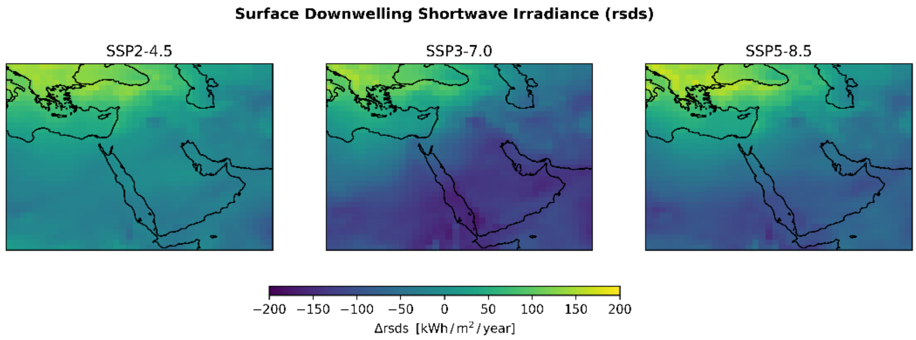

Fig. 1: Differences in mean annual Surface Downwelling Shortwave Irradiance

3.2. PV power potential

Figures 2 and 3 depict the variability of the PV output power within the modelling of systems with fixed panels and dual axis tracking respectively.

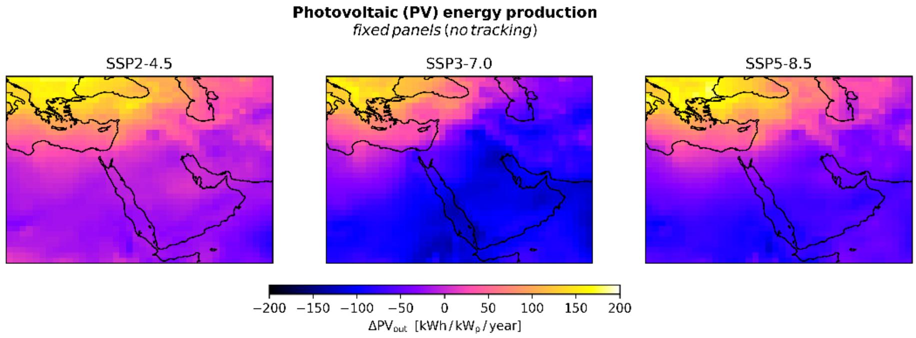

Fig. 2: Differences in mean annual PV power generation within the modelling of systems with fixed panels

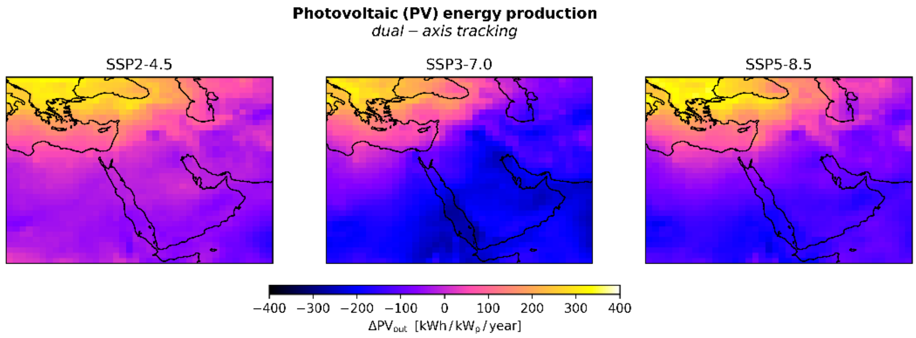

Fig. 3: Differences in mean annual PV power generation within the modelling of dual-axis tracking systems

The patterns indicate that PV energy production is expected to decrease in the Middle East and increase in the Eastern Mediterranean. Figures 1–3 highlight the need for a more detailed analysis of the role of clouds and atmospheric aerosols.

4. References

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