World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

Assessment of solar photovoltaic potential variations in Burkina Faso using SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios by 2050

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World Journal of Advanced Research and Reviews, 2025, 28(03), 1882-1894

Publication history: Received 20 October 2025; revised on 20 December 2025; accepted on 22 December 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.3.3993

Abstract

The study assesses climate change and energy transition in Burkina Faso, a country endowed with high solar irradiation. It evaluates the variability of photovoltaic solar potential (PVP) using historical climate data (1985-2014) and future projections (2015-2050) from five CMIP6 climate models under SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios. The analysis focuses on surface solar irradiation and air temperature. Nationally, PVP is projected to decrease by 1.04% (SSP1-2.6) to 3.10% (SSP5-8.5) compared to the historical period. The most significant reductions are expected to affect dry and semi–arid areas, which were previously the most suitable for solar energy production. The high-emission scenario SSP5-8.5, associated with severe global warming, results in the most substantial losses, particularly in the northern and eastern parts of the country. Despite this projected decline, these areas still hold the greatest potential. These findings underscore that, even under climate change, solar energy remains a viable and crucial option for meeting Burkina Faso's growing energy demand, reducing dependence on fossil fuels, and mitigating greenhouse gas emissions. However, the siting of large-scale PV fields must consider climate zones to limit future variability in energy production.

Keywords: Solar potential; Photovoltaic energy; Climate change; Shared Socioeconomic Pathways (SSPs); Burkina Faso

1. Introduction

Solar photovoltaic (PV) technology is a crucial pathway to decarbonization and universal electricity access within the global energy transition. Sub–Saharan Africa, mainly characterized by persistent electrification deficits but endowed with exceptional solar resources [1], is a key region for its adoption. Burkina Faso, located in West–Africa has a national grid that remains small and heavily dependent on imported fossil fuels, despite rapidly growing energy demand. Consequently, solar PV has emerged as a viable option to enhance energy security and diversify the country's energy mix.

Climate conditions, however, may significantly influence PV conversion efficiency [2, 3] West Africa (WA) is characterized by intense cloudiness, elevated temperatures, and frequent dust events, all of which have a negative

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impact on solar PVP [4, 5, 6]. Photovoltaic plants require substantial financial investment and often reduce vegetation cover. Moreover, climate change is predicted to alter the atmospheric conditions that affect solar PVP. It is therefore essential to account for potential climate change impacts when planning long-term PV development, generation, and management strategies in the region. Several studies in West Africa and across Africa have examined the implications of climate change on solar energy potential [7, 8, 9, 10]. These studies generally project a decline in future solar PVP. Most of them, however, relied on models from the Coupled Model Intercomparison Project Phase 5 (CMIP5) under Representative Concentration Pathway (RCP) scenarios [11]. By contrast, the new Shared Socioeconomic Pathways (SSPs) explicitly integrate socioeconomic variables such as population, land use, and emissions, thereby providing more comprehensive scenarios for future climate evolution [12, 13, 14, 15]. The new generation of climate models, CMIP6 [16], builds on these SSPs through the Scenario Model Intercomparison Project (ScenarioMIP) framework [17], offering enhanced representations of human and societal development pathways [16, 18]. Furthermore, CMIP6 has demonstrated improved performance compared to CMIP5 in producing historical climate patterns across several regions worldwide [19, 20, 21, 22], although its applicability in West Africa remains underexplored. Previous studies have mainly focused on quantifying changes in solar PVP. For instance, an extreme warming scenario was projected to reduce solar PVP in West Africa by about 4% [10]. Building on these insights, our study applies advanced CMIP6 models to assess future solar energy potential in Burkina Faso, with particular attention to the SSP5-8.5 pathway [23]. Unlike earlier research, this work provides a country-specific analysis for Burkina Faso, combines multiple SSP scenarios, and highlights regional disparities in PV potential within the country. It therefore offers both scientific insights and practical guidance for policymakers and investors planning long-term solar deployment strategies.

In this context, the objective of this study is to evaluate climatic data in relation to solar energy potential in Burkina Faso, focusing on 1985 - 2014 and projecting toward the end of the mid-century under three scenarios: SSP1-2.6, SSP2-4.5, and SSP5-8.5.

The paper is structured as follows: Section 2 presents the study area, data, and methods. Sections 3 and 4 respectively discuss the results and provide an in-depth analysis, while section 5 concludes the paper.

2. Material and methods

2.1. Study area

Burkina Faso is a landlocked Sahelian country located in West Africa, spanning latitudes 9° N to 15° N and longitudes 6° W to 3° E. It covers an area of approximately 274 200 km^2 and is characterized by a strong north-south gradient in precipitation and high interannual climate variability. Figure 1 shows the location of Burkina Faso in West Africa, and Figure 2 illustrates its four main climatic zones: arid, semi-arid, dry sub-humid, and wet sub-humid.

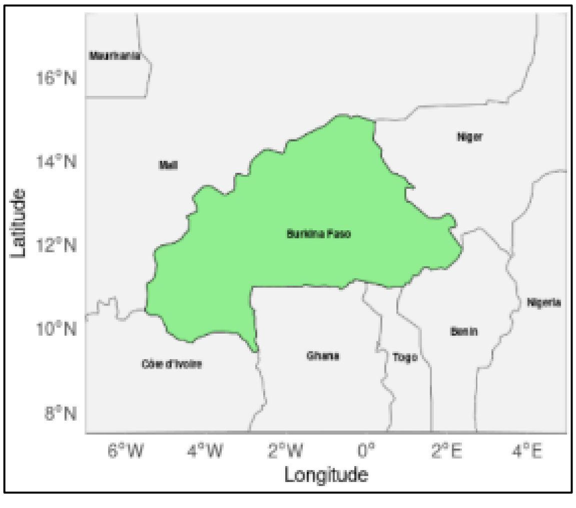


Figure 1 Study region

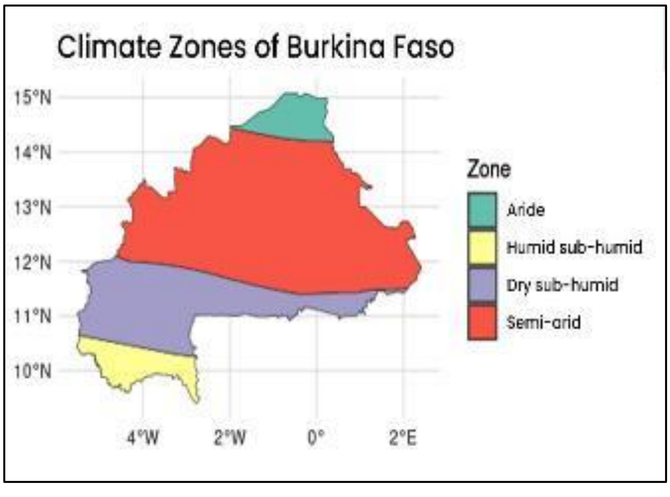


Figure 2 Burkina Faso's climatic zones

2.2. Used data

The analysis of photovoltaic potential (PVP) relies on both historical and projected climate data. Historical records (1985 - 2014) serve as the reference baseline for evaluating current conditions, while climate projections (2015 - 2050) provide insights into future changes under different emission scenarios.

Table 1 CMIP6 GCMs used, their resolutions and origine Institutions

Model	Resolution	Institution	Reference
ACCESS-CM2	1.875°x 1.25°	CSIRO-ARCCSS(Australia)	[24]
AWI-CM-1-1-MR	0.938°x 0.935°	AWI-CM(Germany)	[25]
BCC-CSM2-MR	1.125°x 1.12°	BCC(China)	[26]
CAMS-CSM1-0	1.875°x 1.875°	CAMS(China)	[27]
CanESM5-CanOE	2.812°x 2.791°	CCCma(Canada)	[28]

The data were drawn from the CMIP6 project, coordinated by the World Climate Research Program (WCRP) and disseminated through the Copernicus Climate Data Store (C3S) [29, 30]. Five climate models (Table 1) were selected under three SSP scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5), resulting in a total of 15 scenario-model combinations for a robust ensemble analysis.

CMIP6 outputs are available at different horizontal resolutions. To ensure consistency, all data were regridded to a 0.25 × 0.25 common grid using bilinear interpolation. This resolution was chosen to balance computational efficiency with the higher spatial detail provided by CMIP6.

2.3. Used shapefile data

To ensure that the analysis focused exclusively on Burkina Faso, a shapefile (gadm41_BFA_0) containing the national administrative boundaries was used to extract climate data restricted to Burkina Faso. This shapefile, version 4.1 and level 0, originates from the Global Administrative Areas (GADM) database, which provides detailed cartographic data of global administrative entities at multiple levels [31].

In addition, a shapefile of climatic zones, extracted from the Atlas of the Directorate of Rural Electrification (SDER) of UEMOA, was used. This dataset provides a regional classification of West African climate zones. Combined with the national boundary shapefile, it allowed us to isolate only the climatic zones located within Burkina Faso, ensuring consistent spatial analysis across administrative and ecological divisions.

2.4. Photovoltaic Potential Estimation

The solar photovoltaic (PVP) potential was estimated using a physical model derived from [32]. This model utilizes the surface effective radiation, I_s (W/m^2), at an ideal inclination angle, and the near-surface air temperature, Ta (°C). The PVP, expressed in Watts (W), is calculated as:

$$PVP\ (i, t) = B.I_s(i, t)(1 - \mu(T_a(i, t) - T_{c,STC}) - \mu.C.I_s(i, t)) \qquad (1)$$

Specifically:

The efficiency coefficient B is the product of the solar panel's surface area, the photovoltaic generator performance, and the inverter efficiency.

The temperature-dependent factor μ and the radiation-dependent factor C account for efficiency losses in photovoltaic conversion.

$T_{c,STC}$ denotes the standard operating temperature of photovoltaic cells.

The constants B, μ, and C vary with the specific photovoltaic technology employed.

In this study, we consider a photovoltaic generator rated at 1 kilowatt-peak (kWp), adopting the same technical assumptions as *Danso et al.* (2022) [23].

The selected technical parameters are $T_{c,ST}$ C = 25°C; μ = 0.028%; B = 0.004 %/°C; $B = 10 \times 0.16 \times 0.8$ (where the composite value integrates the module surface area of 10 m^2, panel efficiency of 16%, and inverter efficiency of 80%). For small-scale solar potential assessments, a 10 m^2 surface is commonly assumed for a 1 kW peak system

2.5. Estimation of prospective solar PV generation changes

The prospective change in solar photovoltaic potential (PVP) is calculated following the methodology of *Danso et al.* (2022) [23]. The relative change (ΔPVP) between future (PVP_{fut}) and historical (PVP_{hist}) generation periods is given by:

$$\Delta \boldsymbol{PVP} = \frac{PVP_{fut} - PVP_{hist}}{PVP_{hist}} \times \mathbf{100} \qquad \mathbf{2}$$

2.6. Software and tools for data processing

All data processing, analysis, and visualization were carried out using the R programming language [33] (version 4.4.0), an open-source environment for statistical computing and geospatial analysis. The main tasks performed in R included:

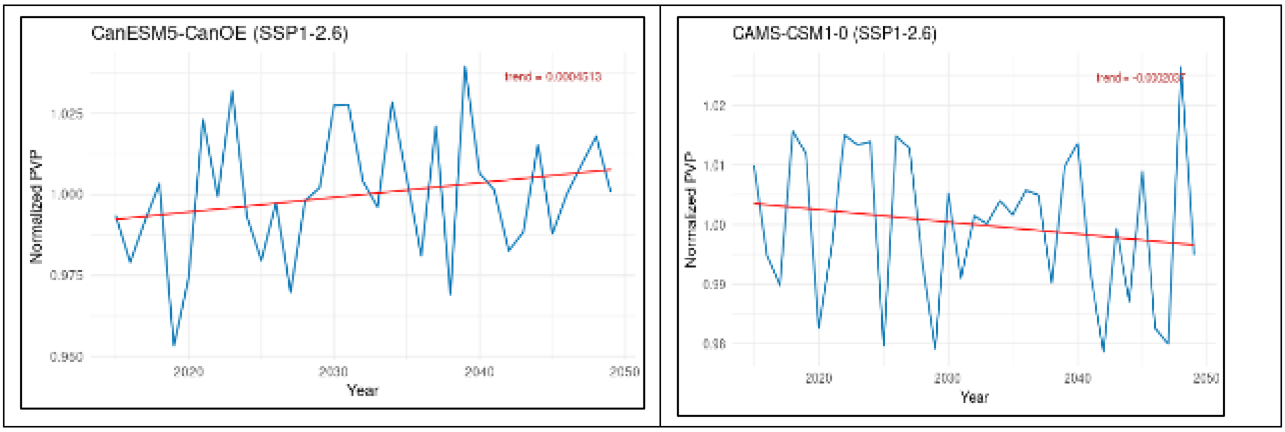
- Importing, manipulating, and extracting zonal statistics from NetCDF climate datasets.
- Applying spatial masking and temporal aggregation procedures.
- Implementing the PVP physical model using near-surface air temperature and solar irradiance.
- Producing graphs, thematic maps, and results tables.

In addition, Climate Data Operators (CDO) [34] software was employed for complementary preprocessing steps.

3. Results and discussion

3.1. Changes in future solar PVP generation according to SSP1-2.6 scenario

Figure 3 shows near-term (2015-2050) changes in solar PVP under SSP1-2.6. While two models suggest an increase, most indicate a decline, making reduced solar resources the more likely outcome. This aligns with CMIP6 findings for West Africa, where lower solar radiation is linked to cloud and atmospheric changes [23, 8]. The agreement across models strengthens confidence, as multi- model means are more reliable than single outputs [11].



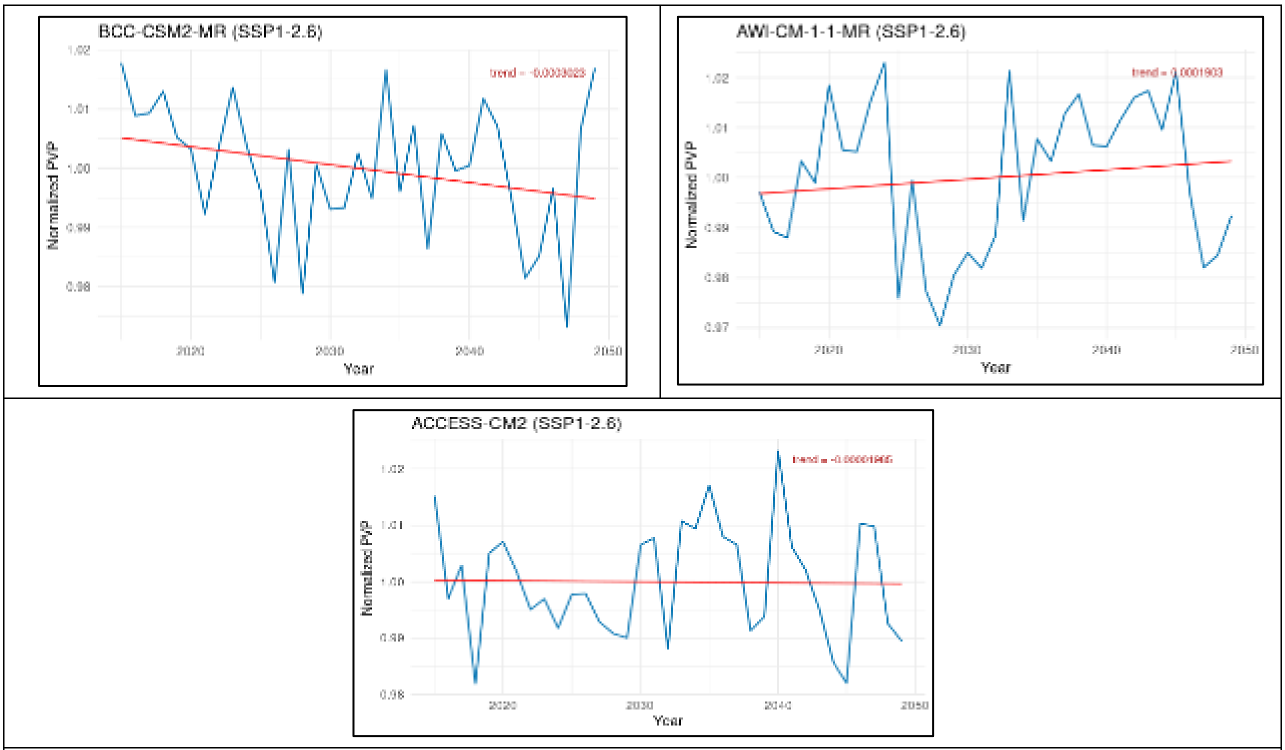
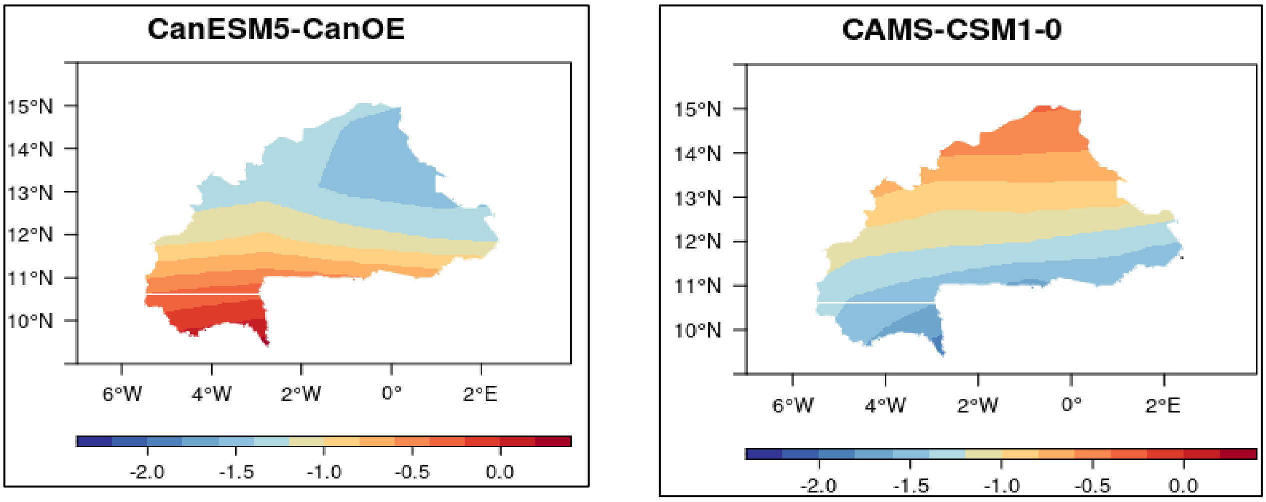


Figure 3 Projected PVP under SSP1-2.6 over the period 2015-2050

Figure 3 shows projected PVP changes under SSP1-2.6 (2015-2050), with all models indicating a nationwide decline. Southern regions, especially the sub-humid dry and wet zones, face the greatest losses, raising concerns for energy security. Strong inter-model agreement boosts confidence by reducing bias uncertainty [16, 11]. These results align with CORDEX-AFRICA studies linking reduced solar resources to cloud and circulation changes [8, 10], confirming a robust climate-change signal.



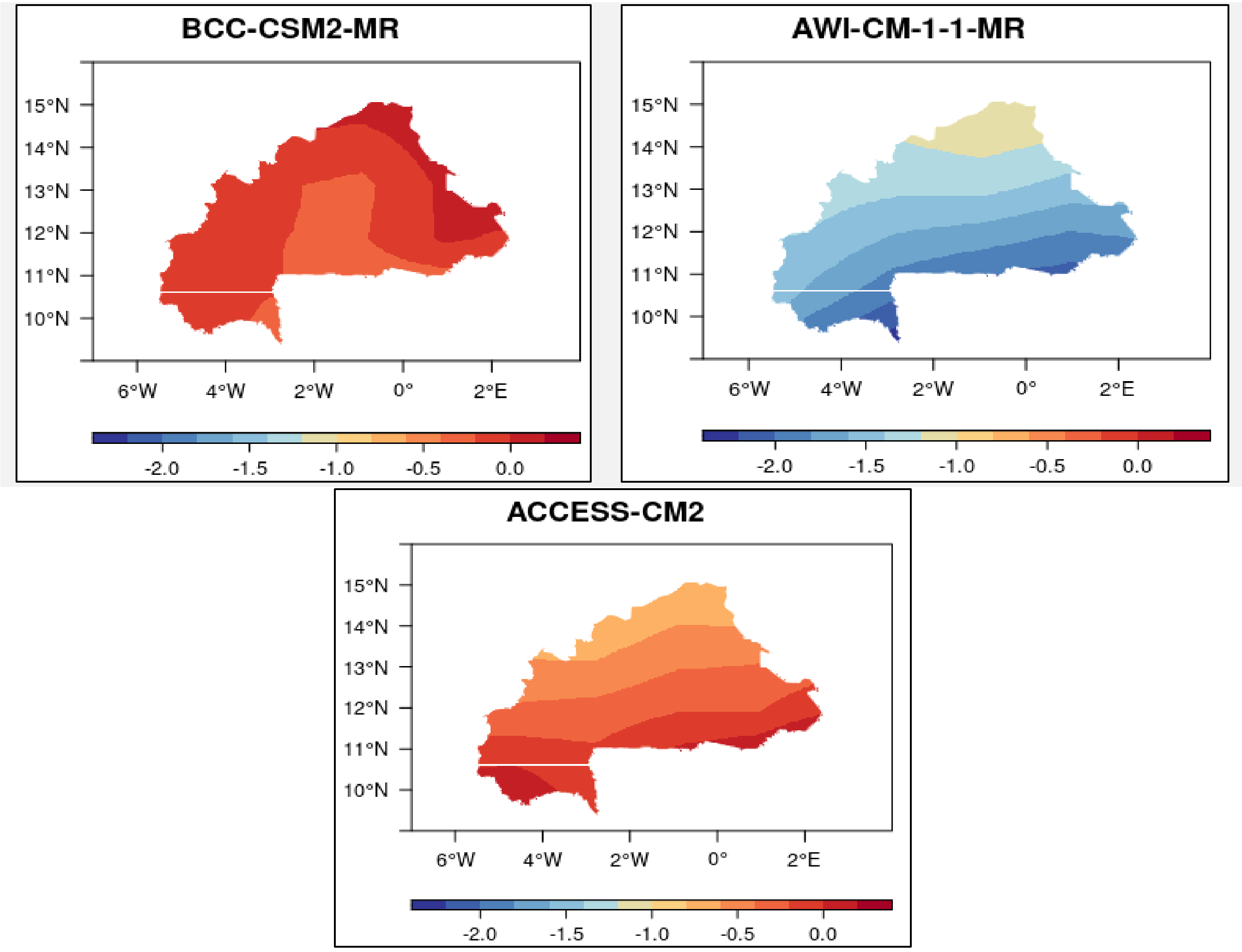
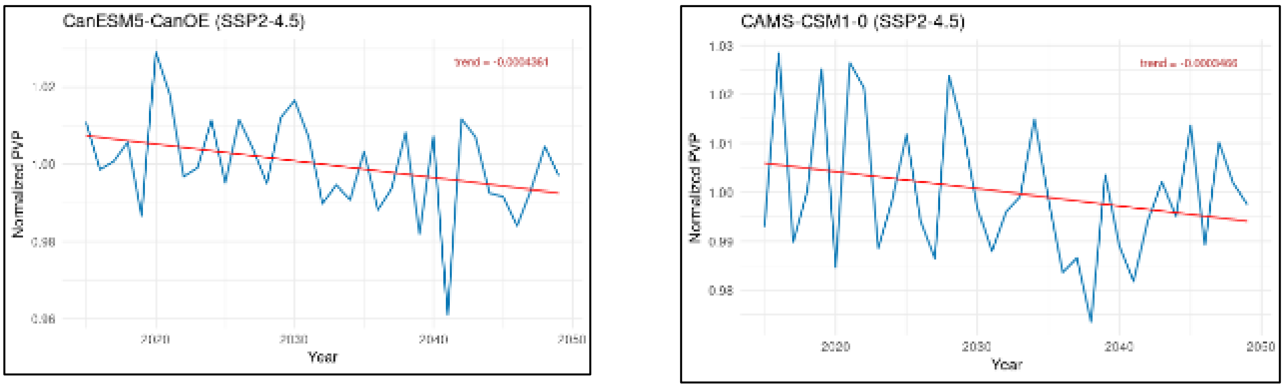


Figure 4 Spatial distribution of future PVP changes under SSP1-2.6

3.2. Changes in future solar PVP generation according to SSP2–4.5 scenario

Figure 4 shows that under SSP2-4.5, all models project a consistent decline in Burkina Faso's PVP. This unanimous signal, free from individual model biases, strongly increases confidence in the projection [16, 11]. The decline is linked to increased cloud cover and aerosols reducing surface irradiance [23, 4]. These results highlight urgent implications for energy security, calling for storage, grid flexibility, and diversification of renewables [32].



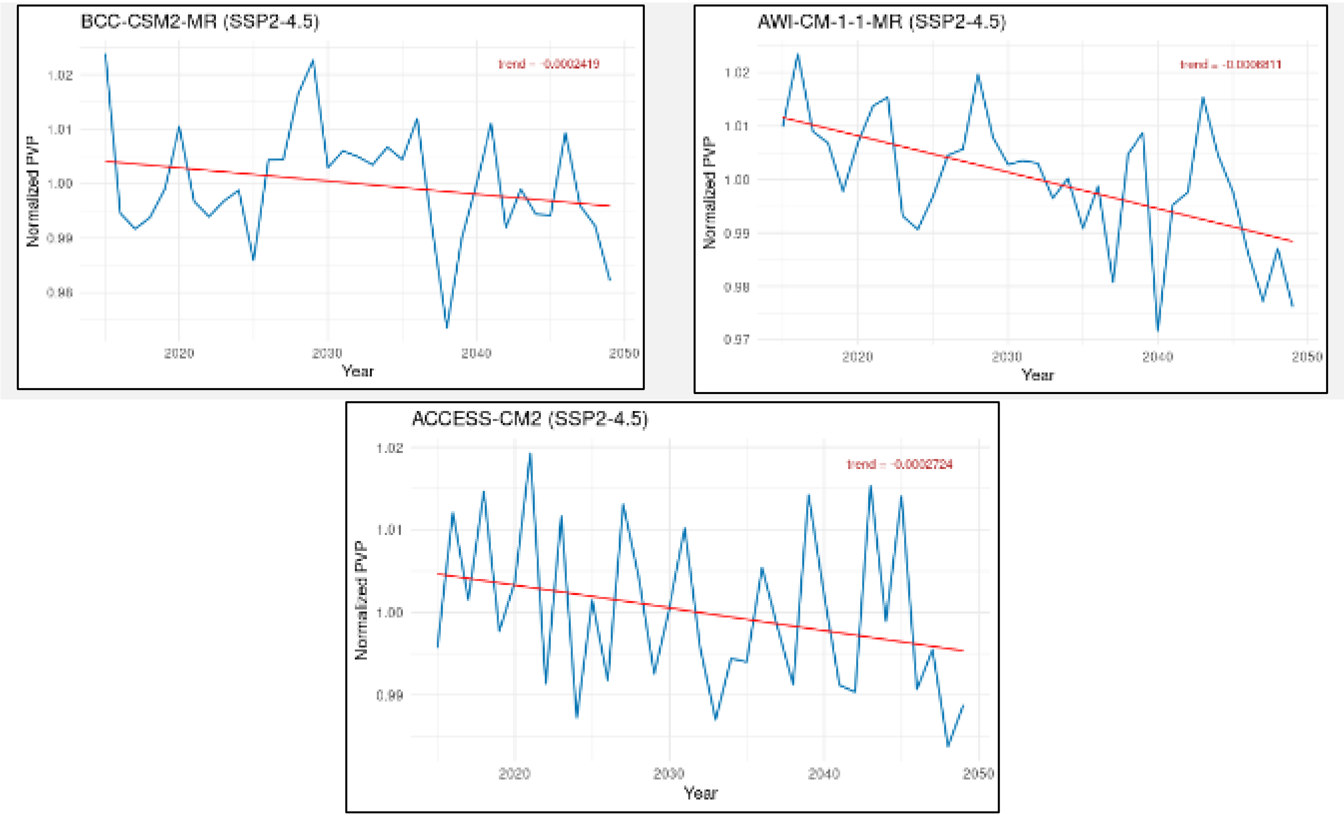
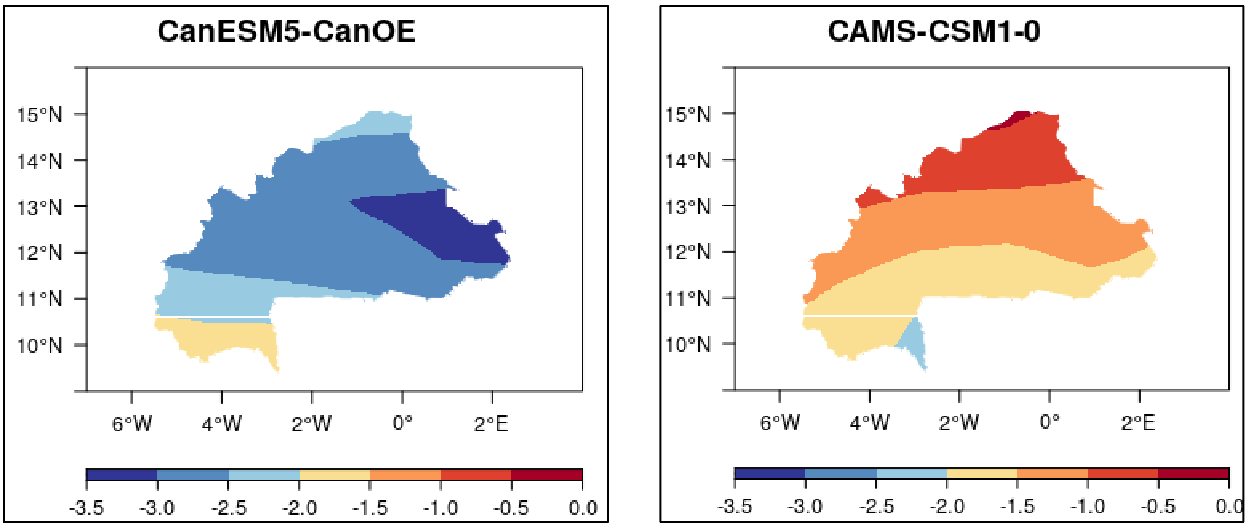


Figure 5 Projected PVP under SSP2-4.5

Likewise, figure 6 shows that under SSP2-4.5, all models project a nationwide decline in PVP for 2015-2050, confirming a robust climate-change signal [16, 11]. Indeed, models ACCESS-CM2 and CanESM5-CanOE indicate the strongest losses in the northern arid and semi-arid zones, likely due to increased dust aerosols [4, 2], whereas models BCC-CSM2-MR and CAMS-CSM1-0 show larger decreases in the southern sub-humid zones, linked to enhanced cloudiness from monsoon changes [6, 5]. This divergence highlights that adaptive strategies must consider both northern and southern vulnerabilities for energy planning and solar infrastructure [8, 10].



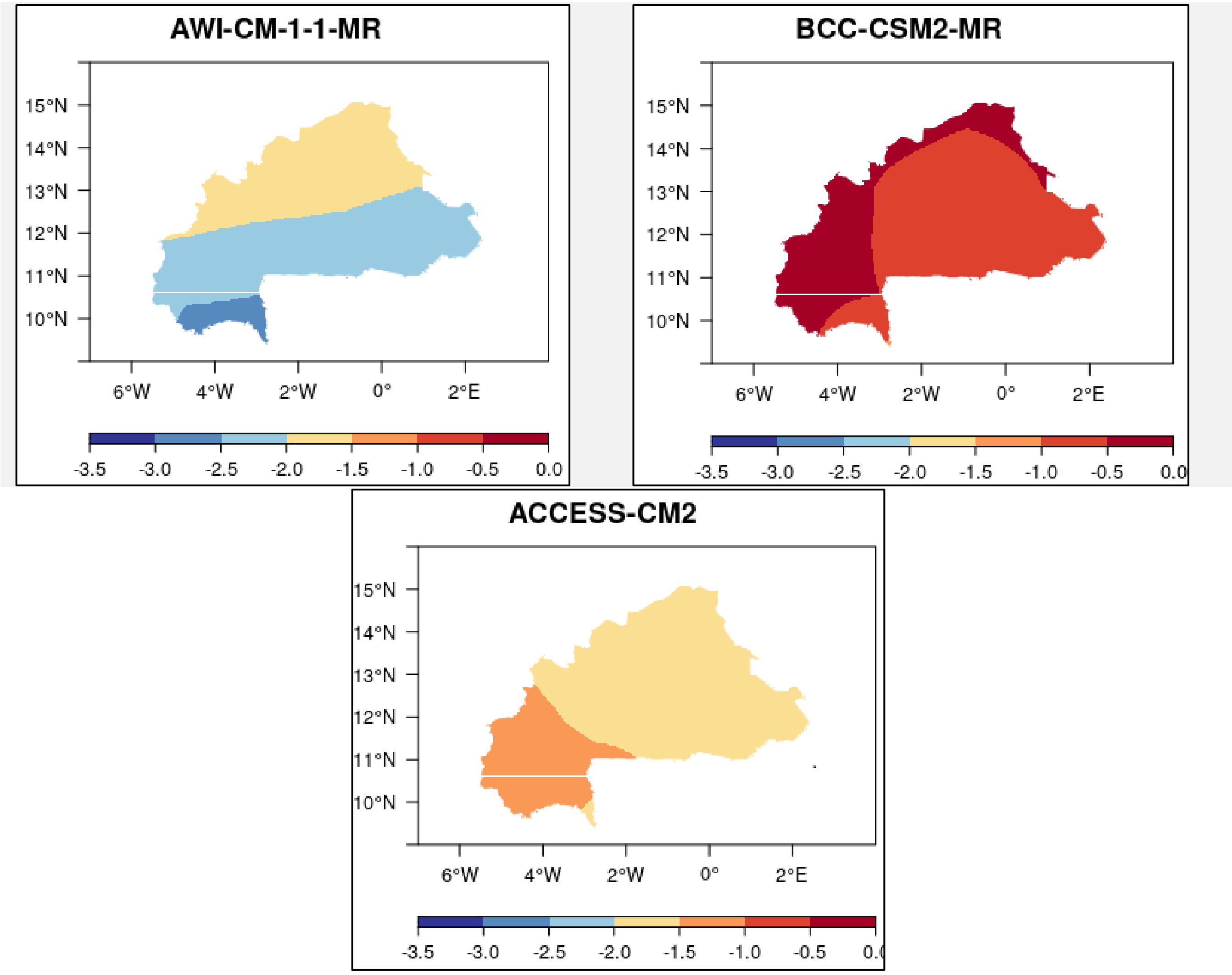
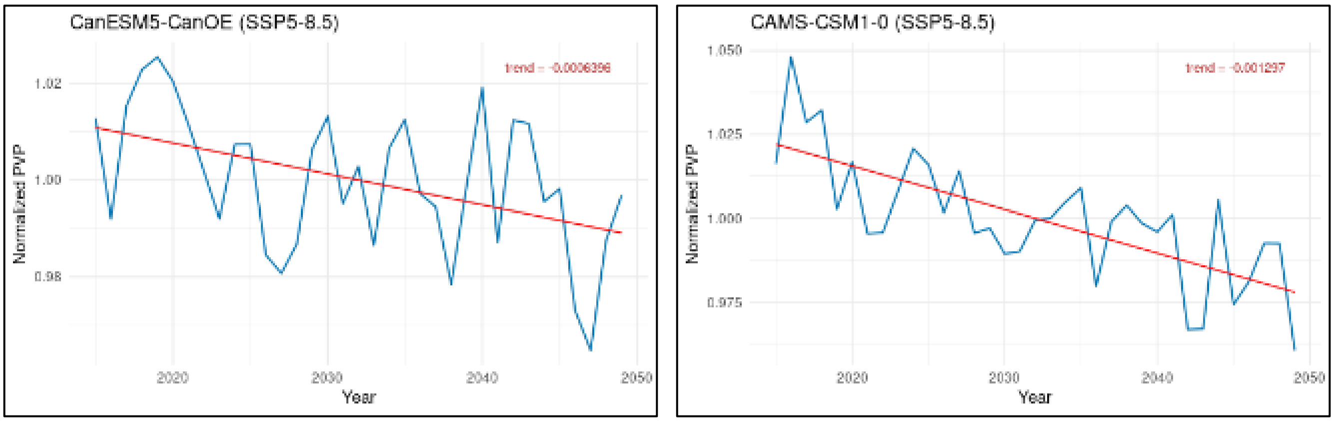


Figure 6 Spatial distribution of future PVP changes under SSP2-4.5

3.3. Changes in future solar PVP generation according to SSP5-8.5 scenario

The projected future solar photovoltaic potential (PVP) under the high-emission SSP5-8.5 scenario (Figure 7) shows a unanimous and alarming downward trend across all models. This strong inter-model agreement signals a robust and high- confidence climate change impact, with intensified atmospheric forcing driving consistent reductions in surface solar radiation, likely via enhanced cloud cover and aerosol effects [23, 16, 11]. These findings highlight the serious risk that unchecked climate change poses to the reliability and security of solar energy, emphasizing the urgent need for adaptive planning and resilient energy strategies.



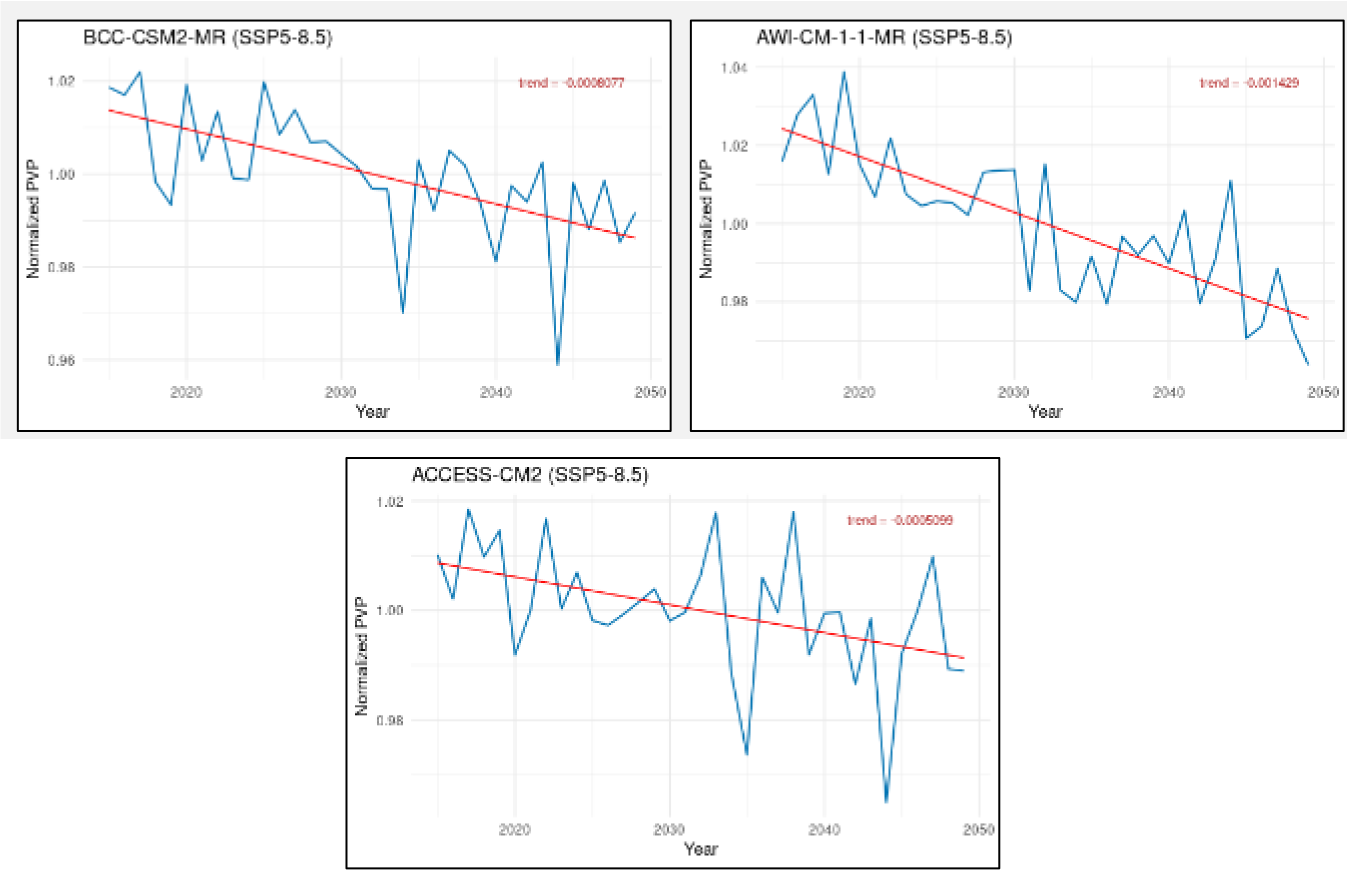
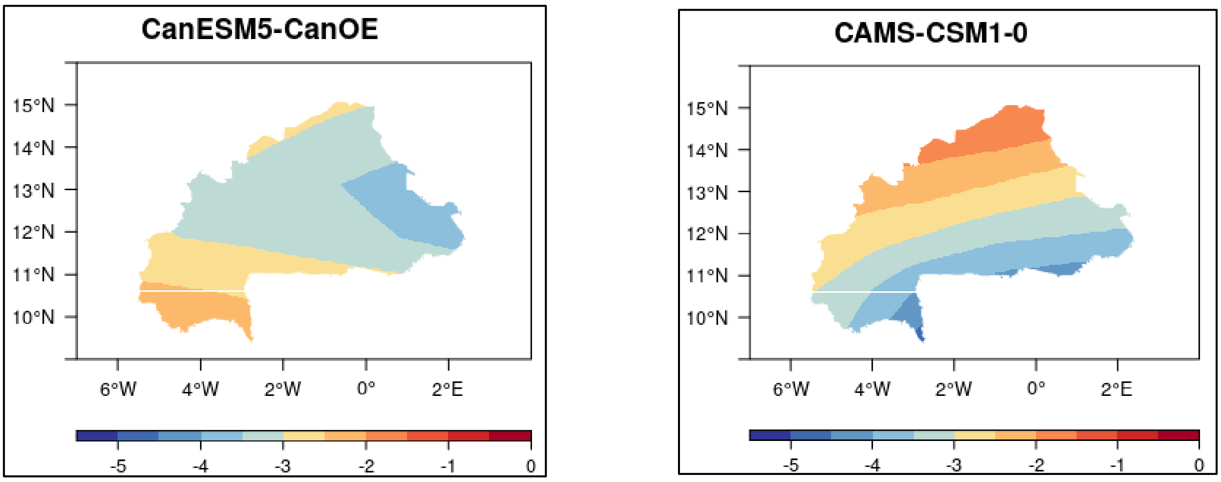


Figure 7 Projected PVP under SSP5-8.5

Figure 8 shows a clear, nationwide decline in solar PVP under the high-emission SSP5-8.5 scenario, with all models agreeing on this severe threat to Burkina Faso's solar resource [23]. Most models project the strongest losses in the northern arid and semi-arid regions, consistent with enhanced dust aerosols and extreme warming under strong radiative forcing [4, 8]. While model (a) differs regionally, the ensemble consensus confirms a robust signal of widespread PVP decline, characteristic of CMIP6 multi-model assessments [16].



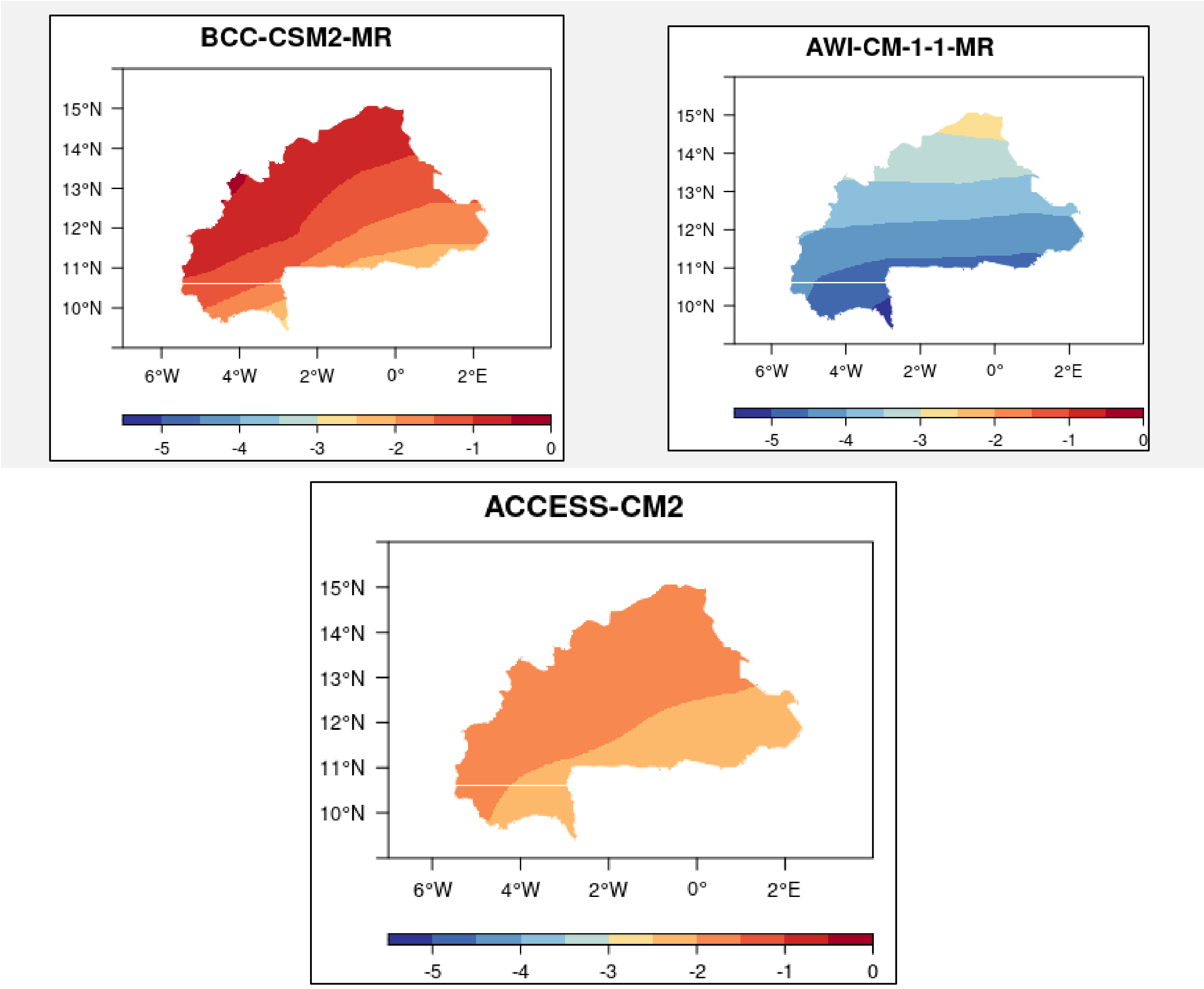


Figure 8 Spatial distribution of future PVP changes under SSP5-8.5

3.4. Changes in future solar PVP across climatic zones

Cartographic analysis reveals a consistent decline in solar photovoltaic potential (PVP) across Burkina Faso's climatic zones, with the magnitude of loss intensifying under higher- emission scenarios, a pattern consistent with CMIP6-based projections for West Africa [23]:

- The semi-arid zone is the most affected, exhibiting the greatest decline of 3.31% under the SSP5-8.5 scenario.
- The arid zone also shows substantial vulnerability, with a reduction of 3.05% under SSP5-8.5.
- The dry sub-humid zone is subject to a considerable decrease, with a loss of 2.82% under SSP5-8.5.
- The wet sub-humid zone is the least impacted, experiencing a minimal decline of 0.10% under SSP1-2.6. However, its losses increased markedly under more pessimistic scenarios.

These findings indicate that semi-arid and arid zones, which comprise a substantial portion of Burkina Faso, are likely the most vulnerable to a decline in solar energy potential over the coming decades. This heightened vulnerability in drier regions could be linked to projected increases in atmospheric dust loadings and changes in cloud cover patterns, which are critical atmospheric drivers of solar irradiance [4,6,3]. The sub-humid dry zone also experiences moderate reductions, while the sub-humid wet zone is comparatively less affected, particularly under low-emission scenarios. Table 2 accurately quantifies these variations depicted in Figures 6 and 8, confirming a general decrease in photovoltaic potential at the national level, aligning with studies that project a reduction in solar resource potential for West Africa under climate change [8, 10]. Moreover, the findings highlight that adopting low-emission pathways, such as SSP1-2.6, can substantially mitigate losses compared to higher- emission scenarios, underscoring the importance of climate policy for resilient energy planning [14].

Table 2 Variation (%) in future PVP by climate zone

Climatic Zones	SSP1-2.6	Institution	SSP5–8.5
Arid	- 1,26	- 2,86	- 3,31
Semi–arid	- 1,40	- 2,48	-3,05
Sub–humid dry	- 0,10	- 1,84	- 2,32
Sub–humid wet	-0,67	-2,41	- 2,82

4. Conclusion

This study assessed the temporal and spatial variability of solar photovoltaic potential (PVP) using historical data (1985-2014) and future climate projections (2015-2050). Five climate models were applied, focusing on two key variables: solar radiation and air temperature. Past and projected PVP were analyzed to identify spatio–temporal trends. The main findings are:

- All scenarios indicate a national average increase in PVP compared to the historical baseline, ranging from +11.43% under the optimistic SSP1-2.6 to +9.10% under the pessimistic SSP5-8.5.
- The intermediate (SSP2-4.5) and pessimistic (SSP5-8.5) scenarios predict a decrease in PVP by 2050, while the optimistic scenario (SSP1-2.6) maintains relatively stable potential.
- The northern regions of the country remain the most favorable for solar development due to consistently high irradiance.

These findings underscore the strategic importance of solar energy for Burkina Faso. Even within the context of climate change, the country can leverage its significant solar potential by adopting sustainable energy policies. Solar PV technology is particularly well-suited for decentralized energy systems, which can reduce dependence on centralized grids and enhance energy security, especially in remote and off-grid communities. Furthermore, by advancing solar power plant technology and integrating it into the national energy mix, Burkina Faso can make a substantial contribution to a cleaner, more sustainable future while promoting energy resilience and sustainable development.

To build upon these findings, future work should focus on several key areas. First, model robustness could be improved by integrating a broader set of climate variables, including cloud cover, relative humidity, and dust aerosol concentrations. Second, it is crucial to explore how these climate interactions affect a wider range of photovoltaic technologies, such as amorphous silicon, organic solar cells, hybrid cells, and concentrated photovoltaics. Ultimately, more research is needed to fully understand the potential duration and frequency of low solar energy production periods in a future climate.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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