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Research Article

Solar Photovoltaic Energy and Electricity Security on ECOWAS Countries

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The study presented in this paper analyzes the role that photovoltaic energy can play in enhancing energy self-sufficiency in each of the fifteen Economic Community of West African States (ECOWAS) countries. For this purpose, the satellite CM-SAF database, Global Land Cover data and land slope computed from Digital Elevation Model data, was used to compute the area of suitable lands, the potential of energy, and the coefficient of variation of solar irradiation. The results show that 31.76% of the total area of each ECOWAS country has the potential to shelter photovoltaic energy system generators. Except Cape-Verde which lacks data concerning land cover, all the countries of the community dispose of suitable area for photovoltaic systems installation. Using only 1% of these areas at each country scale the amount of the whole community energy production can reach up to 7782.37 TWh·year^{-1}. The result of solar resource repartition shows that the energy could have a low interannual variation. But, in the same year, a significant variation of solar irradiation exits between months.

1. Introduction

The socioeconomic development of a region depends mainly on energy. The fifteen countries which constitute the Economic Community of West African States (ECOWAS) are challenged with threatening factors of energy security such as poor system reliability, limited infrastructure, fuel import dependence, and heavy reliance on fossil fuels, hydropower, and traditional biomass resources [1]. Electricity generation depends on 65% of fossil fuel [1]. Besides, the growing gap between generation capacity and demand is exacerbated by high commercial and technical losses estimated at 21.5% [1]. These factors have made the region have the lowest modern energy consumption rates in the world with average electricity consumption of 120 kWh/capita compared to the continental and global averages of 529 and 2570 kWh/capita, respectively [2]. Spatial data shows that household access to electricity across the region is about 20%. Wide differences exist between the access rates in urban areas (43%), while rural areas range between 6% and 8% [3]. In addition to the environmental pollution due to fossil fuel and limited factors cited above, the lack of energy prevents a suitable development policy for ECOWAS countries. Among the solutions, photovoltaic (PV) system is noticed like one of the best applications in the generation of solar energy [4]. Added to the clean energy production, this technology has become the main research topic of many researchers and led to an increasingly powerful technology at a lower cost [5].

Furthermore, in the context of climate change, diversification of energy sources is necessary to transit to the so-called clean energies. Some countries like the United States of America, Germany, and Japan have realized the advantages and made this technology popular [6].

In favor of its geographical location, solar power appears to be good for increasing access to electricity in West Africa and to improve people's living conditions [7]. There are two kinds of solar technologies: the flat-plate PV modules and the concentration PV modules, while, in concentrating solar system, efficiency can reach up to 30% or more [8]. Nevertheless, concentration PV module systems require water mainly for cooling purposes in the steam cycle but also to clean the vast mirror areas [9]. More ECOWAS countries are located in sensitive region to climate change; the knowledge of PV electricity potential is useful to policy makers for reducing greenhouse gas emissions from electric energy production. Large concentrated solar power installations require large domains. So, the major problem regarding the implementation of solar power is mainly to find suitable area for the project that also guarantees economic feasibility. This study aims at evaluating the contribution of produced electricity from fixed PV systems mounted at optimum angle for filling the energy demand gap for each of the fifteen countries of ECOWAS. At the same time, the use of this technology should avoid competition between urbanization, environmental protection, and cropland, on the one hand, and electricity production on the other.

To achieve this goal suitable land for PV power generators were identified for each of the fifteen countries, their respective potentials were computed, and finally the solar irradiation coefficient of variation was computed.

Many studies based on the production of energy from PV have been performed in many parts of the world. Domínguez Bravo et al. (2007) [10] define the capacity and generation ceiling for renewable energy technologies for Spain. The electricity generating technologies considered are wind turbines, solar photovoltaic (PV), Concentrating Solar Power (CSP), and biomass. Two solar technologies have been included in the analysis: PV integrated into buildings and PV with tracking. Assuming a certain number of restrictions concerning the suitable area, they find that with tracking systems the generated power can reach up to 708.4 GWp and the demanded area is about 8.82% of the Spanish peninsular territory. Šúri et al., (2007) [11] used monthly and yearly averages of global irradiation and related climatic parameters, from 19811990. They first analyzed the regional and national differences of solar energy resource and then assessed the photovoltaic (PV) potential in the 25 European Union member states and 5 candidate countries. They found that PV can already provide a significant contribution to a mixed renewable energy portfolio in the present and future European Union. An investigation of Van Hoesen and Letendre (2010) [12] concerning regions in Poultney, in Vermont, USA, has shown that regions with the highest average solar radiation values are located in areas with difficult access. Results also suggest moderate potential for utilizing building specific solar technologies and, under current land use scenarios, poor potential for developing a larger-scale array close to downtown, which consumes most energy. The potential of renewable energy reserves in Taiwan has been examined by Chen et al. (2010) [13]. The study reveals that while natural conditions are good, land conditions are very inadequate for the installation of solar equipment in Taiwan. According to their estimation, the reserve of solar energy is up to 24.27 kWh/d/p (kWh per day per person). In his study based on Denver State, Janke (2010) [14] found that the ideal areas for solar farms are located east and in the northwestern part of the state. Other researchers are mainly focused on punctual data. Ayompe and Duffy (2014) [15] have assessed the energy generation potential of photovoltaic systems in Cameroon using derived solar radiation datasets. The study based on 33 stations' data revealed a simple payback period of 5.6 years and leveled cost of electricity generation of 6.79 EUR/kWh can be achieved in the region with annual electricity generation of 1764 kWh/kWp if the capital cost of PV systems is 1500 EUR/kWp. An investigation of Elhadidy and Shaahid (2000) [16] has shown that PV systems can harness the portion of demand in desert environment of Saudi Arabia. Ramdé et al. (2013) [7] use Concentrating Solar Power technologies for assessing the electricity on ECOWAS. The used criteria are as follows: Direct Normal Irradiation (DNI) greater than or equal to 5 $\mathrm{kWh \cdot m^{-2}}$, land slope less than or equal to 5%, and distance to transmission line not more than 100 km. They found that West Africa has a potential nominal capacity of 21.3 GW for parabolic trough technology.

2. Methodology

2.1. Assessment of Suitable Land. Some similar studies of Fluri (2009) [17] and Ramdé et al. (2013) [7] consider the proximity of the transmission lines, the land slope, and land cover for the suitable land assessment. Considering the lack in infrastructure of electric energy transport in West Africa, the transmission lines criterion was not considered. Two types of data were used for assessing the suitable land. It concerns land cover and land slope data. Land cover was acquired from the Global Land Cover 2000 database [18, 19] with 1 km × 1 km resolution. These data reveal thirteen categories of land for the region presented in Table 1. For some reasons like protecting natural areas and population diet, forests, cropland, and pasture are excluded of the suitable land. Difficulties linked to the use of water bodies exclude these areas of suitable land. Also urban and built-up land are excluded in order to avoid competition between energy installation and population and secondly the supplementary cost that such project can imply. Land slope data were taken from the Global Land Cover Facility of the Shuttle Radar Topography Mission (SRTM) with a Digital Elevation Model (DEM) [20] with a resolution of 1 km × 1 km. Only land with slope between zero and five was kept. Similar values were taken by Ramdé et al. (2013) [7]. This criterion is considered in order to mitigate the shadows on PV generators, which alter their performances and reduce their productivities [21] and for avoiding supplementary cost associated with the civil work [7].

To get the final suitable land, the two pieces of data were resampled in the same resolution. Then they were overlaid to create a third sample of data. Only cells which are intersections between two suitable cells of the former data were used.

2.2. Potential of Energy. The computation of the PV systems energy requires the high precision of sunlight knowledge. Two data sources are usable: ground measurements data from

Table 1: Land cover type and criteria for PV technologies.

land cover type	Decision
Urban and built-up land	Unsuitable
Dryland cropland and pasture	Unsuitable
Irrigated cropland and pasture	Unsuitable
Cropland/grassland mosaic	Suitable
Cropland/woodland mosaic	Suitable
Grassland	Suitable
Shrubland	Suitable
Savanna	Suitable
Deciduous broadleaf forest	Unsuitable
Evergreen broadleaf forest	Unsuitable
Water bodies	Unsuitable
Herbaceous wetland	Unsuitable
Barren or sparsely vegetated	Suitable

radiometers and satellite-derived calculated data. Twenty-two radiometer sites were counted across West Africa and distributed as follows: Burkina Faso (5), Ghana (6), Guinea (2), Mauritania (3), Nigeria (3), and Senegal (3) [15]. The low density of the existing networks of radiometers could be explained by their high costs and the requirement of specific and periodic calibrations [22]. High sensitivity of these devices in case of lacking maintenance and short-term data recording does not guarantee high accuracy of data. For this study, daily averages from satellite-derived solar radiation datasets with a spatial resolution of 0.5 × 0.5 which range from 1983 to 2013 were used. They were taken from Satellite Application Facilities data on Climate Monitoring (CM-SAF) [23]. The daily values of solar radiation were used to compute the yearly sum of irradiation on tilted plane (G) through the package solaR [21]. So, the electricity generated from flat-plate PV modules was determined by using [24]

$$E = \eta S G, \quad (1)$$

where E is the electricity generated, η is the PV system efficiency fixed at 22.8% [25], S is the total solar panel area (m^2), and G is yearly sum of irradiation on PV module with tilted plane ($kWh{\cdot}m^{-2}$).

2.3. Solar Radiation Variability. The West African climate is mainly characterized by a low humidity and high temperatures during the period March, April, and May mainly in northern countries. This situation increases the energy demand in order to support the climatic effects. The rare hydropower plants are in the lowest production rate due to lack of water. In this section, the annual and monthly and monthly intrayearly coefficient of variation (COV) of solar resources were computed. Knowledge of this variability is important for improving the design of a PV generator system in order to respond to the demand. The daily averages values of solar radiation defined in the previous section were used to compute the yearly averages, monthly averages per year, and the considered period monthly averages using the Climate Data Operators (CDO 2015: Climate Data Operators,

Table 2: Potential area of PV Energy.

Country	Suitable land area (km^2)	Proportion of total territory (%)
Côte d'Ivoire	82068.77	25.56
Ghana	95595.67	39.78
Liberia	28825.64	30.13
Burkina Faso	119292.42	43.53
Guinea	92902.50	37.42
Guinea-Bissau	10376.45	33.05
Mali	335023.56	26.63
Senegal	44797.81	22.69
Sierra Leone	18608.87	25.45
The Gambia	3240.87	32.51
Benin	37011.19	31.23
Niger	306313.96	25.86
Nigeria	403432.74	44.17
Togo	17373.39	30.92

available at https://www.mpimet.mpg.de/cdo). The 31 yearly average values of solar irradiation are the inputs for annual COV. The annual and monthly COV were computed by using monthly means of solar irradiation with this formula [26]:

$$C_t = 100 \times \frac{\sigma_t}{E_t}, \quad (2)$$

where C_t is the COV expressed in percentage, σ_t is the standard deviation of the dataset, and E_t is the mean of solar irradiation. As COV measures the distribution of data points in a data series around the mean, this information would allow understanding how solar resources have varied from 1983 to 2013. The level of significance was set at 5%. The data were therefore assumed to have a Gaussian distribution. For 95% interval of confidence of data we need to go up to two times the value of COV, so the COV was multiplied by two. All these presented data and methodology in this section were computed using the free software R [27].

3. Results

3.1. Potential for Suitable Land Area. The suitable land for PV energy systems in ECOWAS region is presented in Figure 1. The total area of the potential land is 1593863.85 km^2 which represents 31.76% of the ECOWAS territory. More details are presented in Table 2. The first column presents the countries, the second the area of the suitable land for all these countries, and the third proportion of these areas compared with the total territory. Nigeria, for example, has the highest area with 403313.96 km^2, which represents 44.17% of the total territory. The lowest identified area is in Gambia with 3240.87 km^2, which is equivalent to 32.51% of total territory. Cape-Verde is the only country which has no suitable area for PV generator systems according to this study criterion.

3.2. Energy Potentiality. Results of yearly PV production ($TWh{\cdot}year^{-1}$) by each type of suitable land are presented

Table 3: Energy potentiality (TWh·year^{-1}) of ECOWAS countries by suitable land type.

Country		Cropland grassland mosaic	Cropland woodland mosaic	Grassland	Shrubland	Savanna	Barren or sparsely vegetated
Côte d'Ivoire	CIV	2.84	7774.96	108.75	0.00	27143.48	428.70
Ghana	GHA	11.77	11182.15	47.08	12.63	30538.29	846.95
Liberia	LBR	17.73	6882.42	103.97	0.00	4864.43	0.42
Burkina Faso	BFA	0.00	6747.70	4166.46	309.58	46706.46	227.32
Guinea	GIN	0.00	4250.23	20.78	3.09	38260.17	23.53
Guinea-Bissau	GNB	0.00	455.45	43.97	39.73	4377.94	0.00
Mali	MLI	0.00	4689.99	11428.23	14592.65	71379.26	69813.18
Senegal	SEN	0.00	1739.34	2234.18	515.32	17184.87	182.30
Sierra Leone	SLE	1.25	3589.54	1.24	0.40	4547.70	9.94
The Gambia	GMB	0.00	358.98	6.74	1.93	1208.98	5.77
Benin	BEN	0.00	461.72	34.14	2.75	16825.14	8.48
Niger	NER	0.00	3370.05	36333.21	20811.00	6499.80	99016.40
Nigeria	NGA	9.65	21141.91	2694.66	134.47	163243.41	681.52
Togo	TGO	0.00	1081.27	29.76	0.44	6766.33	0.00

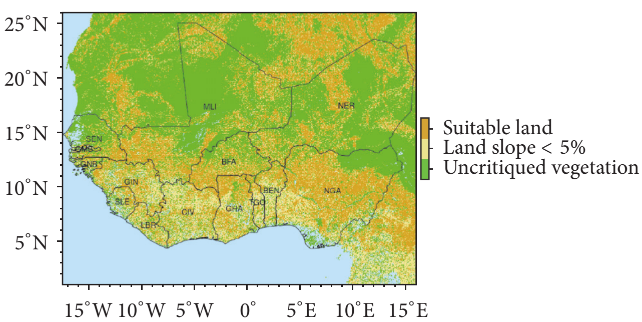


Figure 1: Suitable land for PV power systems generator.

in Table 3, while the results of yearly PV production (TWh·year^{-1}), percentage of the future electricity demand estimated by the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREE) [28], and energy/person/day (kWh/P/D) are presented in the Table 4. It shows that 7782.37 TWh·year^{-1} of PV electricity can be produced by year over the whole ECOWAS region using only 1% area of suitable land found at the precedent section. At each country level, 1% of area production can supply the forecast demand by 2030 according to ECREE. The absence of data concerning the Cape-Verde prevents deriving a logical conclusion on this country. Column 3 of Table 4 is obtained by dividing the forecast demand on electric energy by the results presented in column 1 of the same Table. Concerning the population, the results show that the highest mean repartition of energy is 286.20 kWh/P/D for Mali, and the lowest one is 22.51 kWh/P/D for Gambia. The used data on population was taken from the ECOWAS database [1].

Table 4: Energy potentiality of ECOWAS countries.

Country	Yearly PV production (TWh·year^{-1})	% of the future demand	Energy/person/day (kWh/P/D)
CIV	354.59	2275.91	42.52
GHA	426.39	1482.68	45.35
LBR	118.69	18.75	79.47
BFA	581.58	20478.00	86.76
GIN	425.58	13853.45	101.62
GNB	49.17	6.97	79.57
MLI	1719.03	30582.33	286.20
SEN	218.56	2589.27	43.91
SLE	81.50	5221.06	38.87
GMB	15.82	1171.28	22.51
BEN	173.32	4054.32	46.73
NER	1660.30	67246.04	260.44
NGA	1879.06	1269.21	29.06
TGO	78.78	1757.65	29.36

3.3. Solar Resources Coefficient of Variation. The magnitude of the annual and monthly COV is shown in Figures 2, 3, and 4, respectively, for a threshold level fixed at 5%. Table 5 summarizes the mean of all COV computed by country. At the annual scale the values are not significant and remain below 5%. The solar irradiation COV for the 14 states of ECOWAS (excluding Cape-Verde) ranges from 2.18% in Niger to 3.46% in Liberia. The examination of the results on monthly scale indicates significant COV, which varies from 3.70% for the month December in Burkina Faso to 15.61% for the month of July in Liberia. In general, a contrast between August, October, September, and other months is striking. By considering the means of the twelve months presented in the last column of Table 5, the results of the COV show that great

Table 5: COV means per country.

Country	Yearly	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Intermonthly
CIV	3.00	7.08	8.34	7.71	6.56	7.94	10.06	12.29	12.04	9.82	9.36	6.77	6.81	20.40
GHA	2.65	6.31	7.53	7.66	6.76	7.78	9.08	11.93	12.09	10.35	9.59	5.78	5.12	20.09
LBR	3.46	9.47	9.21	7.49	7.71	8.68	11.77	15.61	12.93	10.51	9.35	7.82	8.62	21.46
BFA	2.24	5.33	5.94	7.10	7.50	7.27	6.57	8.30	11.80	8.74	6.38	4.61	3.70	13.48
GIN	2.44	6.94	6.71	5.91	6.15	7.97	8.78	10.41	11.64	8.23	7.82	6.97	5.98	18.43
GNB	2.68	8.85	8.57	4.84	4.52	8.13	8.83	11.49	11.89	9.49	7.73	6.95	8.78	23.33
MLI	2.34	10.35	9.06	8.18	7.36	7.56	6.50	5.47	7.54	7.31	7.45	6.26	7.29	23.94
SEN	2.29	10.56	9.82	6.94	4.70	7.19	6.46	7.66	10.76	8.78	7.14	7.39	9.47	22.70
SLE	2.87	8.69	6.39	6.57	7.58	8.26	11.21	12.54	13.09	10.30	8.73	7.37	7.81	23.13
GMB	2.37	9.92	9.85	5.83	4.32	7.20	7.02	7.85	11.50	8.97	6.80	7.20	9.69	22.17
BEN	2.51	4.58	6.15	7.59	7.24	7.70	7.54	10.50	13.32	10.59	8.28	5.12	4.18	19.35
NER	2.18	7.68	6.26	8.16	6.37	6.73	5.50	4.88	6.19	5.38	4.87	4.16	6.71	23.08
NGA	2.69	5.31	6.23	8.01	8.08	7.94	8.09	11.26	14.01	10.21	8.34	5.59	5.11	19.95
TGO	2.57	4.93	7.24	8.04	7.28	7.46	8.21	11.02	12.89	9.40	8.03	5.57	4.55	19.39

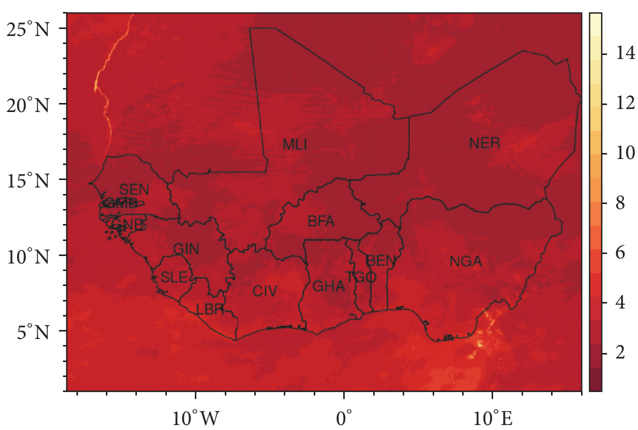


Figure 2: Annual solar resources coefficient of variation.

contrast exits between the months of the same year. The COV ranges from 13.48% in Burkina Faso to 23.94% at Mali.

4. Discussion

This study assesses the potential of centralized flat-plate PV systems on each country of ECOWAS. With only 1% of 1593863.85 km^2 suitable land, the whole ECOWAS PV electricity potential is approximately 7782.37 TWh·year^{-1}. That corresponds to an installed power of 888.40 MW with a regional average of 63.54 MW by country. The country based repartition is unequal, with Mali at the first place with a potential 2.63 times the value of the regional average, followed by Niger and Nigeria with 1.75 and 1.56 times the regional average, respectively. PV potential would have been expected to favor high latitudinal countries but based on the selection criteria another trend was observed. Another challenge is to deal with the connection to electric grid characterized by high expansion cost and its vulnerability to climate changes [29]. As an example, the 225 kV line from Bolgatanga (Ghana) to Ouagadougou (Burkina Faso), around 206 km, costs about $74M [30].

The results of the monthly and annual COV indicate a weak variation for the first while the second presents large variation. Solar irradiation depends on clouds, aerosols, and other atmospheric constituents [31]. Prevention of power fluctuations is of considerable importance to solar PV. Zell et al. (2015) [32] suggested that these variability statistics can be useful for understanding the impact of a variable resource on the output consistency of flat-plate PV.

The present results can be analyzed upstream and downstream. The first sides and the relatively small ranges of interyearly COV values show a small variation in clouds cover and aerosols. The large ranges of monthly interyearly COV are due to large variation in cloud cover and aerosols. The large ranges of monthly intrayearly COV are due to seasonal variations. In terms of power fluctuations, a large range of power fluctuations is observed between the months of the same year. As a solution to this situation, colocation of solar and wind power, suggested by Bozonnat and Schlosser (2014) [31], can be examined in further study. With the high power fluctuations highlighted in monthly intrayearly COV, such installations must be the most accurate in order to face the high energy demand during dry season.

It can be said that, with such a high solar photovoltaic energy potential, there are many options for establishing a 100% renewable generation which can fix the total demand for electricity of ECOWAS members.

5. Conclusion

Required samples of data have been gathered and computed in order to determine the potential of centralized flat-plate PV systems energy for the West African countries. Based on criteria which are most compatible with environmental protection, a land slope less than 5%, the map of suitable land has been drawn. By the mean of package solaR, the global irradiation which reaches the West African surface has been calculated. The results show that 1593863.85 km^2 which

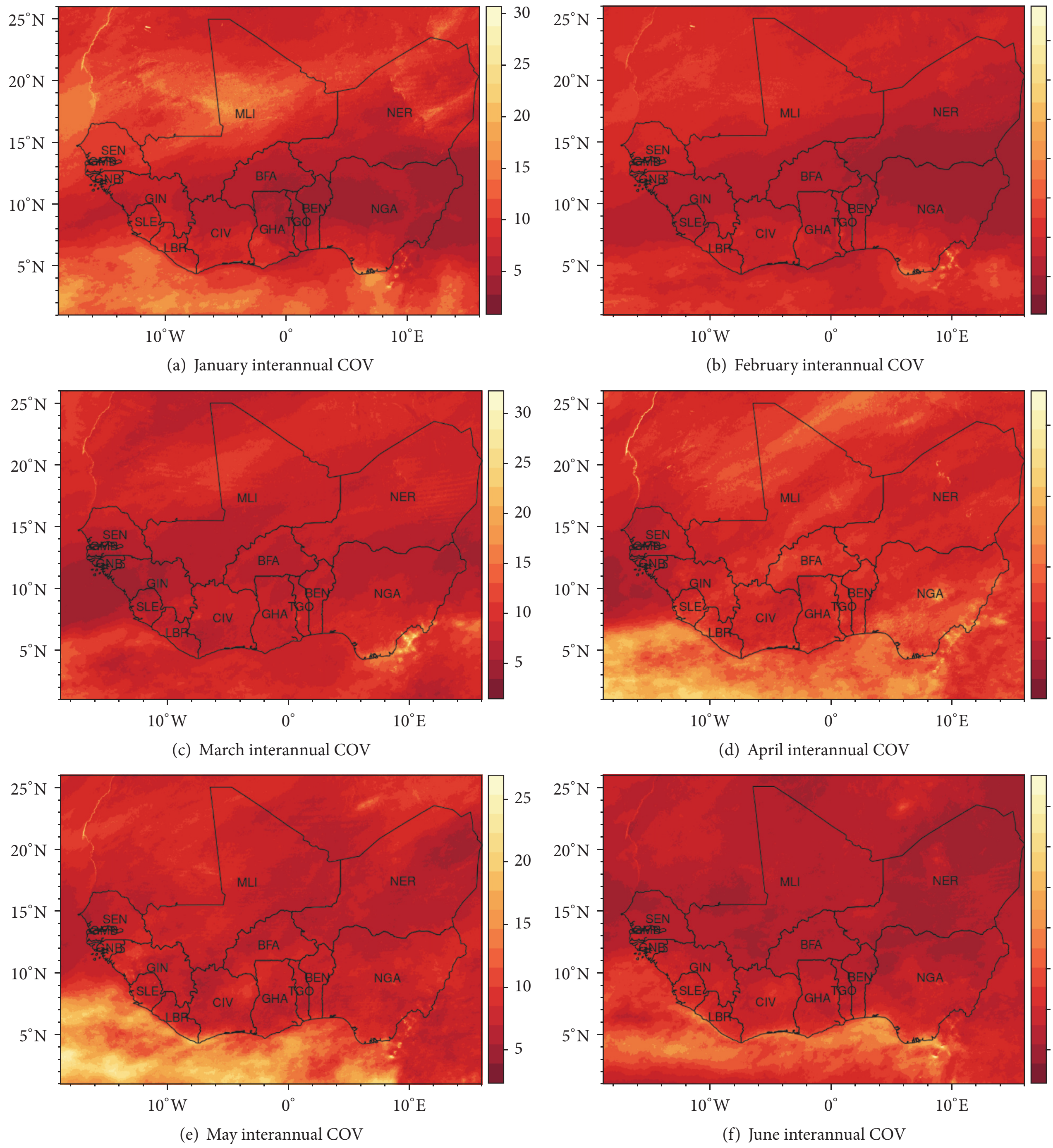
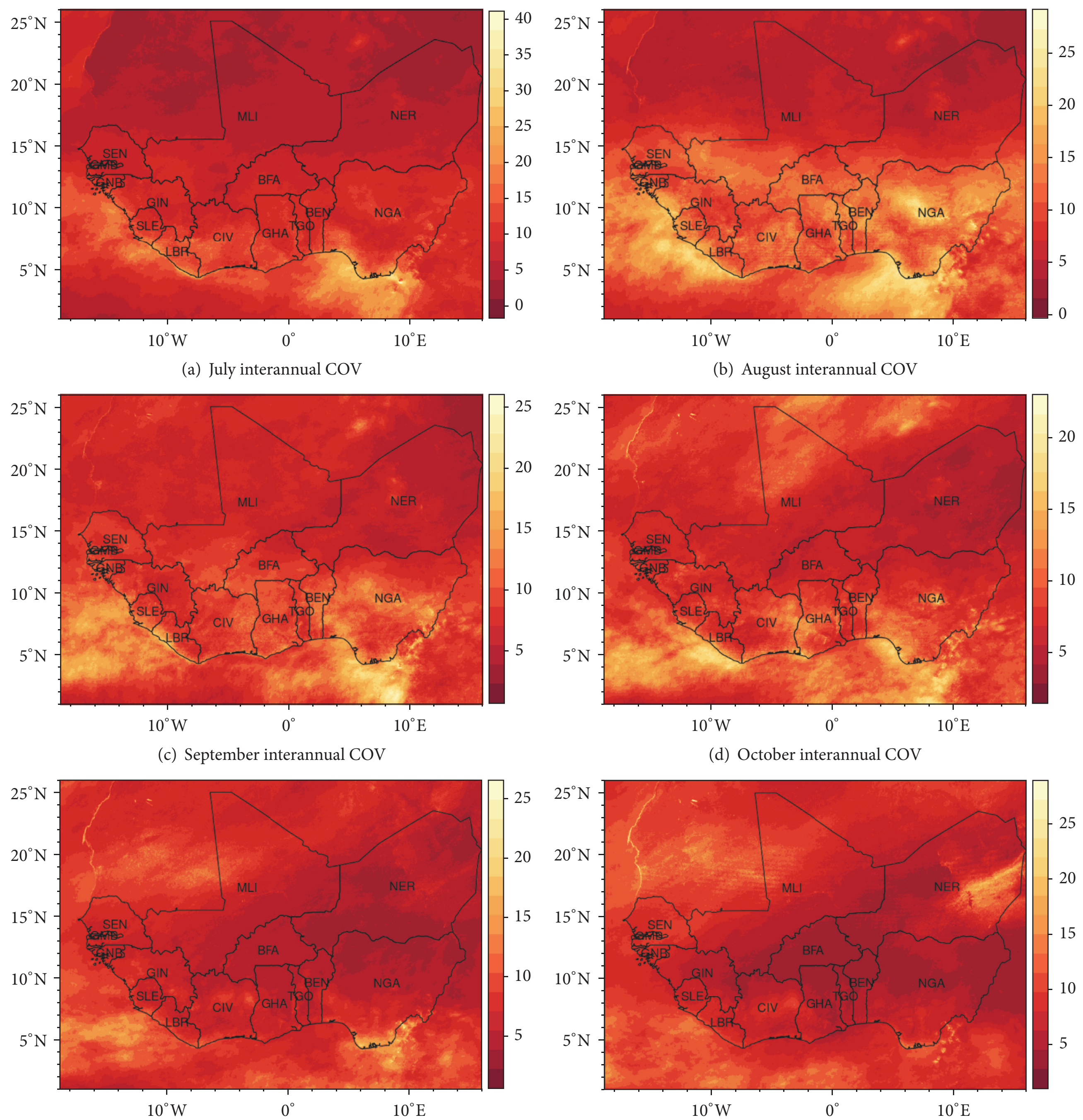


Figure 3: Monthly solar resources coefficient of variation.

represents 31.76% of ECOWAS land is suitable to shelter PV systems. Also 1% of this suitable land approximately 7782.37 TWh·year^{-1} covers the forecasted electric energy demand of all countries. The seasonal analysis of the solar irradiation shows that the solar power is quite constant during all the year. Indeed on annual scale the COV remains below 3.46%, while on a monthly scale the COV can reach up to 15.61% for the month of July.

The present study shows an assessment of the potential of large fixed PV generators in ECOWAS countries. Further studies could be based on the assessment of the best suitable solar technologies which can be used in each part of West Africa. One could also think about practical solutions on how the vast desert with the low population density and the sunniest areas of ECOWAS could be used to produce solar energy. More factors such as rain, temperature, and



(a) July interannual COV
(b) August interannual COV
(c) September interannual COV
(d) October interannual COV
(e) November interannual COV
(f) December interannual COV

Figure 4: Monthly solar resources coefficient of variation (suite).

wind, which influence the PV production, can be added for choosing the suitable land in future studies.

Symbols and Acronyms

η: PV system efficiency
S: Total solar panel area
m^2: Meter square two
$W\cdot m^{-2}$: Watt per square meter
G: Yearly sum of irradiation on PV module with tilted plane
$kWh\cdot m^{-2}$: Kilo-Watt-hours per square meter
C_t: COV expressed in percentage
σ_t: Standard deviation

E_t: Mean of solar irradiation
COV: Coefficient of variation
TWh: Tera-Watt-hours
PV: Photovoltaic
ECOWAS: Economic Community of West African States
ECREEE: ECOWAS Centre for Renewable Energy and Energy Efficiency.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] "ECOWAS Renewable Energy and Energy Efficiency, Status report, 2014," REN21 Secretariat, Paris, France, 2014.

[2] U.S. Energy Information Administration (EIA), International Energy Statistics, 2009, http://www.eia.gov/countries/.

[3] Y. Azoumah, E. W. Ramdé, G. Tapsoba, and S. Thiam, "Siting guidelines for concentrating solar power plants in the Sahel: Case study of Burkina Faso," *Solar Energy*, vol. 84, no. 8, pp. 1545–1553, 2010.

[4] C. Chupong and B. Plangklang, "Forecasting power output of PV grid connected system in Thailand without using solar radiation measurement," *Energy Procedia*, vol. 9, pp. 230–237, 2011.

[5] G. Makrides, B. Zinsser, M. Norton, G. E. Georghiou, M. Schubert, and J. H. Werner, "Potential of photovoltaic systems in countries with high solar irradiation," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 2, pp. 754–762, 2010.

[6] R. Bhandari and I. Stadler, "Grid parity analysis of solar photovoltaic systems in Germany using experience curves," *Solar Energy*, vol. 83, no. 9, pp. 1634–1644, 2009.

[7] E. W. Ramdé, Y. Azoumah, A. Brew-Hammond, A. Rungundu, and G. Tapsoba, "Site Ranking and Potential Assessment for Concentrating Solar Power in West Africa," *Natural Resources*, vol. 04, no. 01, pp. 146–153, 2013.

[8] H. Hong, H. Jin, J. Ji, Z. Wang, and R. Cai, "Solar thermal power cycle with integration of methanol decomposition and middle-temperature solar thermal energy," *Solar Energy*, vol. 78, no. 1, pp. 49–58, 2005.

[9] E. Cohen Gilbert, D. W. Kearney, and G. J. Kolb, "Final Report on the Operation and Maintenance Improvement Program for Concentrating Solar Power Plants," Tech. Rep. SAND99-1290, 1999.

[10] J. Domínguez Bravo, X. García Casals, and I. Pinedo Pascua, "GIS approach to the definition of capacity and generation ceilings of renewable energy technologies," *Energy Policy*, vol. 35, no. 10, pp. 4879–4892, 2007.

[11] M. Šúri, T. A. Huld, E. D. Dunlop, and H. A. Ossenbrink, "Potential of solar electricity generation in the European union member states and candidate countries," *Solar Energy*, vol. 81, no. 10, pp. 1295–1305, 2007.

[12] J. Van Hoesen and S. Letendre, "Evaluating potential renewable energy resources in Poultney, Vermont: a GIS-based approach to supporting rural community energy planning," *Renewable Energy*, vol. 35, no. 9, pp. 2114–2122, 2010.

[13] F. Chen, S.-M. Lu, K.-T. Tseng, S.-C. Lee, and E. Wang, "Assessment of renewable energy reserves in Taiwan," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 9, pp. 2511–2528, 2010.

[14] J. R. Janke, "Multicriteria GIS modeling of wind and solar farms in Colorado," *Renewable Energy*, vol. 35, no. 10, pp. 2228–2234, 2010.

[15] L. M. Ayompe and A. Duffy, "An assessment of the energy generation potential of photovoltaic systems in Cameroon using satellite-derived solar radiation datasets," *Sustainable Energy Technologies and Assessments*, vol. 7, pp. 257–264, 2014.

[16] M. A. Elhadidy and S. M. Shaahid, "Parametric study of hybrid (wind + solar + diesel) power generating systems," *Renewable Energy*, vol. 21, no. 2, pp. 129–139, 2000.

[17] T. P. Fluri, "The potential of concentrating solar power in South Africa," *Energy Policy*, vol. 37, no. 12, pp. 5075–5080, 2009.

[18] S. Channan, K. Collins, and W. R. Emanuel, "Global mosaics of the standard MODIS land cover type data," 2014.

[19] M. A. Friedl, D. Sulla-Menashe, B. Tan et al., "MODIS Collection 5 global land cover: algorithm refinements and characterization of new datasets," *Remote Sensing of Environment*, vol. 114, no. 1, pp. 168–182, 2010.

[20] USGS, *Shuttle Radar Topography Mission, 1 Arc Second Scene SRTM_u03_n008e004, Unfilled Unfinished 2.0, Global Land Cover Facility*, University of Maryland, College Park, Md, USA, 2004.

[21] O. Perpiñán, "solaR: Solar Radiation and Photovoltaic Systems with R," *Journal of Statistical Software*, vol. 50, no. 9, pp. 1–32, 2012.

[22] H. G. Beyer, J. Polo Martinez, M. Suri et al., "Report on benchmarking of radiation products," Management and Exploitation of Solar Resource Knowledge July 2016, 2009.

[23] R. Müller, U. Pfeifroth, C. Träger-Chatterjee, R. Cremer, J. Trentmann, and R. Hollmann, "Surface Solar Radiation Data Set - Heliosat (SARAH) - Edition 1," EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF), 2015.

[24] P. Nema, R. K. Nema, and S. Rangnekar, "A current and future state of art development of hybrid energy system using wind and PV-solar: a review," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 8, pp. 2096–2103, 2009.

[25] Tom Werner, "SunPower Analyst Day," 2015.

[26] S. Wilcox and C. A. Gueymard, "Spatial and Temporal Variability of the Solar Resource in the United States," in *Proceedings of the American Solar Energy Society Conference*, pp. 1–8, 2010.

[27] R Development Core Team, *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria, 2008.

[28] ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), "Baseline Report for the ECOWAS Renewable Energy Policy (EREP)," 2012.

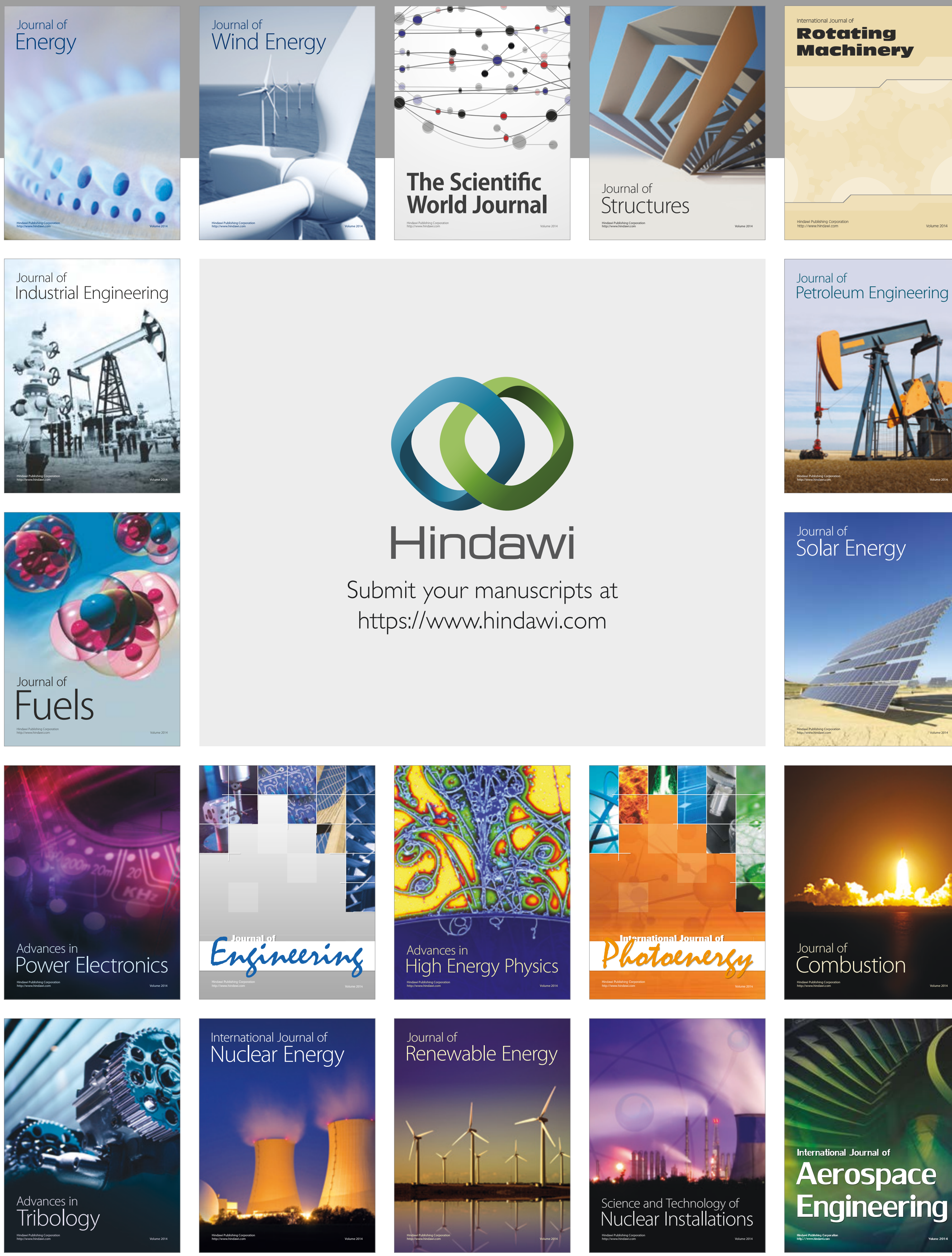
[29] R. Schaeffer, A. S. Szklo, A. F. Pereira de Lucena et al., "Energy sector vulnerability to climate change: a review," *Energy*, vol. 38, no. 1, pp. 1–12, 2012.

[30] West African Power Pool (WAPP), "Update of the ECOWAS Revised Master Plan for the Generation and Transmission of

Electrical Energy Optimal development plan and analysis of transmission network performance and stability. - Final Report Volume 2," 2011.

[31] C. Bozonnat and C. A. Schlosser, "Characterization of the Solar Power Resource in Europe and Assessing Benefits of Co-Location with Wind Power Installations," Tech. Rep. 268, 2014.

[32] E. Zell, S. Gasim, S. Wilcox et al., "Assessment of solar radiation resources in Saudi Arabia," *Solar Energy*, vol. 119, pp. 422–438, 2015.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