ASSESSMENT OF SURFACE DOWNWELLING SHORTWAVE RADIATION IN 2021–2050 IN LAAYOUNE − SAKIA EL HAMRA REGION, MOROCCO

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Abstract

Morocco's energy system is highly dependent on external energy markets. According to the Ministry Energy, Mines and Sustainable Development today more than 93 % of energy resources are imported to Morocco. In 2008 the Moroccan Government has developed a National Energy Strategy, and one of its priority areas is to increase the share of renewable technologies in the country's energy sector. Morocco is rich in solar energy resources. Studies on the assessment of the Morocco's solar energy potential indicate, among other benefits, low additional costs when using solar installations compared to losses associated with the solution of future climate problems and lack of resources. The plan envisages the commissioning of solar power plants in Ouarzazate, Ain Ben Mathar, Boujdour, Tarfaya and Laayoune by 2020.

The aim of this research is determination of the characteristics of the distribution of Surface Downwelling Shortwave Radiation in the area of the solar power Boujdour, Tarfaya and Laayoune, located in the Laayoune − Sakia El Hamra region in 2021–2050. The data from regional climate modeling with high spatial resolution of the CORDEX-Africa project are used in this research. The RCM modeling is carried out for the region of Africa, in a rectangular coordinate system with a spatial resolution of ~44 km. Then, from the modeling data, values are highlighted for the territory of Laayoune − Sakia El Hamra region. Model calculation is performed taking into account the greenhouse gas concentration trajectory of RCP 4.5 calculated using 11 regional climate models. As a result of the simulation for the period 2021–2050, average monthly values of the Surface Downwelling Shortwave Radiation "RSDS" (W/m2) are derived, on the basis of which the mean values for the period of time are calculated. For more detailed information, average monthly total cloud cover values "TC" (%) for the period under study are calculated.

Analysis of the change in RSDS in 2021–2050 relative to the recent climatic period is shown that in the Laayoune − Sakia El Hamra region we can expect an increase or retention of its values. The annual run of the RSDS has one maximum in June and one minimum in December.

In the future, the distribution of RSDS in the Laayoune − Sakia El Hamra region will have a significant impact on proximity to the Atlantic Ocean, where an increased amount of total cloud cover significantly reduces the amount of incoming radiation.

In the location of solar power plants in the near future, the current RSDS values are expected to be maintained, which creates favorable conditions for the further development of the renewable energy industry in this area and increasing its productivity.

Keywords: CORDEX-Africa, Surface downwelling shortwave radiation, RCM, solar energy, Morocco.

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1. Introduction

Morocco's energy system is highly dependent on external energy markets. According to the Ministry of Energy, Mines and Sustainable Development today more than 93 % of energy is imported to Morocco. The state purchases coal for its power plants and petroleum products on the international energy markets. Natural gas is imported from Algeria as compensation for the transit of Algerian gas through Morocco to the south of Spain. From 14 to 20 % of electricity consumed annually in Morocco is imported from Spain via the Strait of Gibraltar [1]. Dependence on international energy markets is a burden on the balance of payments and poses risks to the country's energy security. The growing demand for energy increases the pressure on the Moroccan economy, making the use of alternative energy sources to become the only way out of the current situation.

In 2008 the Moroccan Government has developed a National Energy Strategy, and one of its priority areas is to increase the share of renewable technologies in the country's energy sector. In addition, Morocco launched the renewable energy development program [2], which aims to achieve a total installed capacity of 2000 MW from wind power, 2000 MW from solar energy and an increase in the capacity of hydropower to 2000 MW by 2020 [3].

Morocco is rich in solar energy resources. Studies on the assessment of the Morocco's solar energy potential indicate, among other benefits, low additional costs when using solar installations compared to losses associated with the solution upcoming future climate problems and lack of resources. As part of National Energy Strategy has been developed Moroccan Solar Plan, the main strategic objectives of which are [3]:

– diversification of energy supply;
– preservation of environment;
– exploitation of domestic renewable energy resources;
– reduction of energy dependency.

The plan envisages the commissioning of solar power plants in Ouarzazate, Ain Ben Mathar, Boujdour, Tarfaya and Laayoune by 2020 [4].

In [5] presents the results of assessing the solar potential of Morocco in the current climatic conditions carried out within the framework of the Moroccan Solar Plan. The study used data sets HelioClim 3, HelioClim 1 (average monthly values for the period 1985–2004), and the average values of solar radiation in the period 1981–2000, on the basis of which the calculation of technical and economic indicators for the selection and Substantiation of areas for the placement of Photovoltaic (PV) and Concentrated solar power (CSP) plants on the territory of Morocco.

Concentrated solar power plants usually use parabolic cylindrical reflectors or special tracking mirrors (heliostats) to focus sunlight on a tube or a collector tower, where the heat carrier (liquid or gas) is heated to a very high temperature. Such stations are little dependent on wavelength, and focus direct radiation incoming in the visible, UV and IR ranges, and on cloudy days they can use long-wave radiation of the atmosphere and clouds.

Traditional photovoltaic semiconductor materials, based on which electricity is produced by Photovoltaic power plants, are mainly sensitive to radiation with a wavelength of about 0.4 to

1.1 μm, which is a shortwave part of the spectrum [6–8]. The conversion of solar energy into electric energy, with the help of semiconductor solar cells, is currently the most scientifically and practically developed method.

Regional climate models (RCMs) are the main source of forecasts for possible future climate changes and allow obtaining information with a high spatial resolution for specific regions [9]. In the models, the calculation of the radiation balance at the top of the atmosphere (TOA) and on the underlying surface takes into account the cloud cover, cloud water content, and the size of cloud particles. The observed differences in the results of model calculations and satellite observations are due to the fact that in the models the hydrometeors are provided in a suspended state. excessive surface downwelling shortwave radiation (RSDS) estimates in the calculations of global climate models are caused by underestimates of cloud water content due to the fact that models of the convective cloud core are not taken into account [10]. Thus, total cloud cover is a key component affecting the incoming radiation [11]. Patterns in the change of monthly sum of total radiation under actual cloud conditions are caused mainly by the characteristics of the annual cycle of total radiation and cloud cover [12].

The aim of research is determination of the distribution characteristics of surface downwelling shortwave radiation in the area of the solar power Boujdour, Tarfaya and Laayoune, located in the Laayoune – Sakia El Hamra region in 2021–2050.

2. Materials and methods of research

2. 1. Description of the investigated area

The Laayoune – Sakia El Hamra region is located in the southern part of Morocco, at a latitude from 25 to 28 North latitude, in the west it is washed by the Atlantic Ocean, in the east it borders with Mauritania. The relief in this region is a plain that passes from the accumulative coastal lowlands on the Atlantic coast to the elevated basement plains in the east. In the North-Eastern part of the area penetrate spurs stepped of Draa plateau, much of the territory is covered with sand and dunes of the Sahara desert. The climate in this area is tropical desert, hot in the interior and milder on the coast.

On the territory of the Laayoune – Sakia El Hamra region is one of the richest deposits of phosphates Bou Craa, which reserves exceed 10 billion tons, deposits of uranium, oil and gas. On the coast there are port facilities, industrial plants for the enrichment and desalination of phosphates. The operation and maintenance of these facilities, as well as the development and construction of new ones, require an uninterrupted supply of electricity.

In rural areas, where there are relatively small distant settlements, the creation of centralized energy systems is impractical. In such areas, it is necessary to create autonomous power installations of low power based on the use of renewable energy sources. Currently, one of the main tasks of the Moroccan Government is solving the problem of supplying residents of the Laayoune – Sakia El Hamra region with electricity, hot water, heat or cold supply on the basis of alternative energy sources [13].

The Boujdour, Tarfaya and Laayoune solar power plants are located on the Atlantic coast and have the following characteristics (**Table 1**).

Table 1

Description of sites for solar power plants [5]

Site	Coordinates		Elevation, m	Location	Installed capacity, MW
	φ, °	λ, °			
Boujdour	26.10	–14.47	55	4 km to the north of Boujdour	100
Tarfaya	27.15	–13.20	69	south of the city of Tarfaya	500
Laayoune	27.93	–12.93	7	south of Foum El Oued	500

The population of the Laayoune – Sakia El Hamra region is 256 152 inhabitants, approximately 200 000 habitants lives in Laayoune, 41 178 in Boujdour, and 8 027 inhabitants in Tarfaya.

2. 2. Data and methods

In this study, data from regional climate modeling with high spatial resolution of the CORDEX-Africa project [14, 15] are used. The RCM modeling is carried out for the region of Africa, in a rectangular coordinate system with a spatial resolution of ~ 44 km. Then, from the modeling data, values are highlighted for the territory of Laayoune – Sakia El Hamra region. Model calculation is performed taking into account the greenhouse gas concentration trajectory of RCP 4.5. 11 climate models developed in research institutes and meteorological centers around the world are used for the calculation (**Table 2**). Further, RCM calculations are performed using an ensemble of models to increase the success of reproduction of average climatic characteristics. This is due to the fact that the systematic errors inherent in each model separately are often random in relation to the ensemble of models and are mutually compensated when averaged by the ensemble [16].

Table 2
Regional climate models characteristics

No. of model	Model name	The atmospheric general circulation model	Data centre
M1	KNMI-ICHEC-EC-EARTH	IFS	CNRM, France
M2	CanESM2	CanCM4	CCCMA, Canada
M3	CNRM-CM5	ARPEGE	CNRM / CERFACS, France
M4	SMHI-ICHEC-EC-EARTH	IFS	CNRM, France
M5	CSIRO Mark 3.6	Mk3 AGCM	CSIRO, Australia
M6	IPSL-CM5A-MR	LMDZ	IPSL, France
M7	MIROC5	AGCM CCSR	AORI/NIES/JAME S&T, Japan
M8	HadGEM2-ES	HadGEM2-A	Hadley Center, UK
M9	MPI-ESM-LR	ECHAM6	MPI, Germany
M10	NorESM1	CAM4-Oslo	NCC, Norway
M11	GFDL-ESM2M	AM3	GFDL, USA

As a result of the simulation for the period 2021-2050, average monthly values of the surface downwelling shortwave radiation "RSDS" (W/m^2) are derived, on the basis of which the mean values for the period of time are calculated. For more detailed information, average monthly total cloud cover values "TC" (%) for the period within the study are calculated. The CERES_EBAF-Surface_Ed4.0 data for the 2005–2015 [17] is used as the base values to estimate the change in the amount of surface downwelling shortwave radiation.

3. Experimental researches

The results of the RCMs calculations showed that in 2021–2050 average RSDS value (**Fig. 1**) in Tarfaya will be 235 W/m^2, in Laayoune and Boujdour 242 and 240 W/m^2, respectively. The nature of the distribution of RSDS has a deviation from latitudinal on the Atlantic coast, which is not surprising, since the amount of incoming radiation is significantly affected by cloudiness. As noted [18], the increased amount of total cloud cover on the Atlantic coast of Morocco is caused by the transfer to the continent of clouds formed above the ocean surface. Above the cold waters of the Canary Current, which flows near the coast, favorable conditions are created for the condensation of wet sea air, the formation of fog and low stratus clouds.

Analysis of changes in the incoming RSDS in 2021-2050 relative to the recent climatic period (**Fig. 2**), showed that in the Laayoune – Sakia El Hamra region we can expect an increase or retention of its values. The most interesting is the Atlantic coast, where are located solar power plants and the main objects of economic activity in the region. In the areas of power plants location, the models predict the preservation of the number of RSDSs, and when moving deeper into the region at 70 km, about 10 W/m^2 and more.

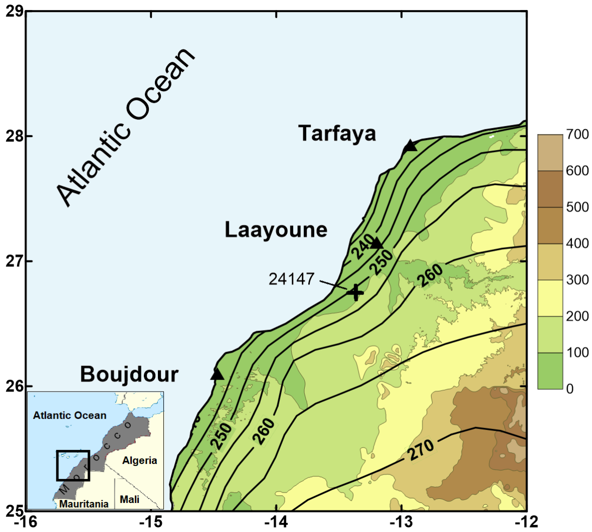
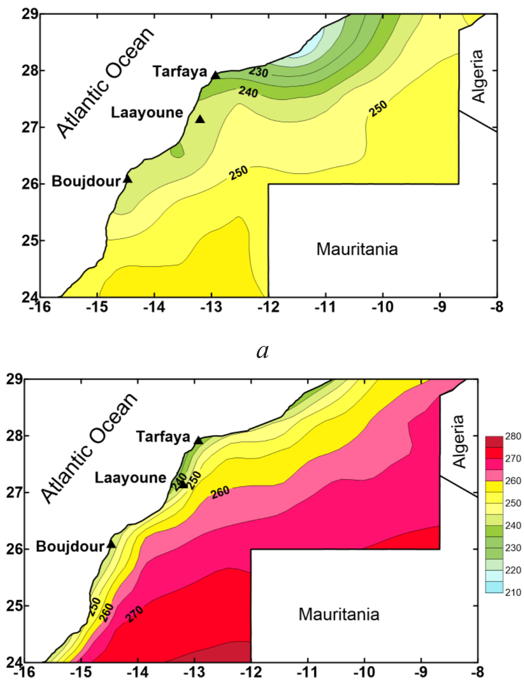


Fig. 1. The location of solar power plants (triangles) and the distribution of the RSDS (W/m^2) in 2021–2050



a

b

Fig. 2. Average value RSDS (W/m^2): *a* – 2005–2015; *b* – 2021–2050

The largest increase in RSDS is expected in the areas adjacent to the border with Mauritania (up to 20 W/m^2), but the remote location and sparse population makes these areas unsuitable for installing solar installations.

The annual run of the RSDS is affected by the course of solar radiation, due to astronomical factors and the annual run of the total cloud cover. In the extratropical latitudes of the Northern Hemisphere, the annual course of insolation has one maximum in June and one minimum in December [19]. The amplitude of the seasonal variations of insolation increases with increasing latitude.

The analysis of the predicted RCM annual run of short-wave radiation is carried out on the basis of calculations of monthly average RSDS values in the 24147 model grid node, located 47 km south of Laayoune (**Fig. 3**). As can be seen from the figure, the expected maximum RSDS falls on the month of June and will be 320 W/m^2.

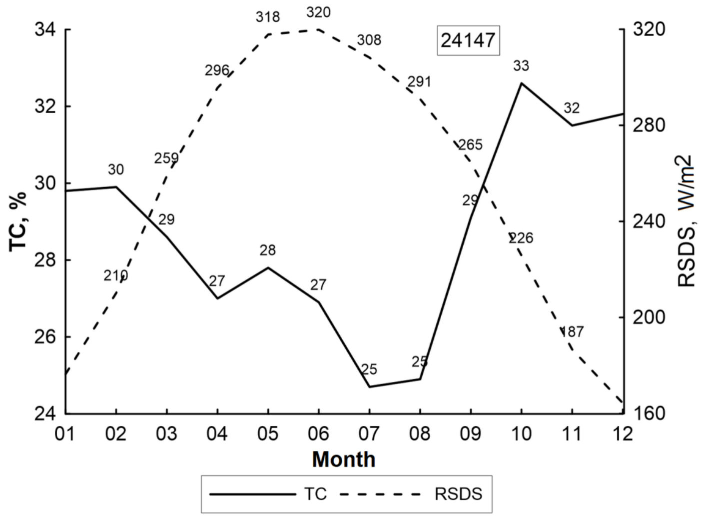


Fig. 3. Annual run of TC (%), and RSDS (W/m^2) in grid node 24147

The average monthly total cloud cover calculated by the RCM in the summer months ranges from 25–27 %, which reduces the amount of incoming radiation.

4. Conclusions

The proximity of the Atlantic Ocean has a significant impact on the distribution of RSDS in the Laayoune – Sakia El Hamra region, where an increased amount of total cloud cover significantly reduces the amount of incoming radiation.

In the location of solar power plants in the near future, the current RSDS values are expected to be maintained, which creates favorable conditions for the further development of the renewable energy industry in this area and increasing its productivity. The projected increase in RSDS is expected in the interior of the region, the remote location of which creates additional costs for the transmission of electricity, which significantly increases its cost and makes these areas less promising from the point of view of solar energy.

References

[1] Nfaoui, H., Sayigh, A. A. M. (2015). Contribution of Renewable Energy to Morocco's Energy Independence. ISESCO Journal of Science and Technology, 11 (19), 90–96.

[2] Borodkina, N. (2015). French renewable energy policy in Morocco in the early 21st Century. Vestnik of Northern (Arctic) Federal University. Series "Humanitarian and Social Sciences", 3, 5–10. doi: https://doi.org/10.17238/issn2227-6564.2015.3.5

[3] Jamae, E. M. (2015). Renewable Energy Transition in Morocco. Renewable Energy Transitions in Jordan and the MENA Region, 23–31.

[4] Moroccan Agency for Solar Energy Projects. Available at: https://www.masen.ma/en/masen/

[5] Richts, C. (2012). The Moroccan Solar Plan – a comparative analysis of CSP and PV utilization until 2020. Available at: https://www.uni-kassel.de/eecs/fileadmin/datas/fb16/remena/theses/batch2/Master-Thesis_Christoph_Richts.pdf

[6] Andreev, V. M., Grilihes, V. A., Rumyancev, V. D. (1989). Fotoelektricheskoe preobrazovanie koncentrirovannogo solnechnogo izlucheniya. Leningrad: Nauka, 310.

[7] Timchenko, S. L., Dementieva, O. J., Zadorozhnyi, N. A. (2015). The Influence on Radiation Spectrum Characteristic Curves of the Solar Battery. Physical education in universities, 21 (1), 3–13.

[8] Bazyomo, S. D. Y. B., Agnidé Lawin, E., Coulibaly, O., Ouedraogo, A. (2016). Forecasted Changes in West Africa Photovoltaic Energy Output by 2045. Climate, 4 (4), 53. doi: https://doi.org/10.3390/cli4040053

[9] Feser, F., Rockel, B., von Storch, H., Winterfeldt, J., Zahn, M. (2011). Regional Climate Models Add Value to Global Model Data: A Review and Selected Examples. Bulletin of the American Meteorological Society, 92 (9), 1181–1192. doi: https://doi.org/10.1175/2011bams3061.1

[10] Li, J.-L. F., Waliser, D. E., Stephens, G., Lee, S., L'Ecuyer, T., Kato, S. et. al. (2013). Characterizing and understanding radiation budget biases in CMIP3/CMIP5 GCMs, contemporary GCM, and reanalysis. Journal of Geophysical Research: Atmospheres, 118 (15), 8166–8184. doi: https://doi.org/10.1002/jgrd.50378

[11] Katragkou, E., García-Díez, M., Vautard, R., Sobolowski, S., Zanis, P., Alexandri, G. et. al. (2015). Regional climate hindcast simulations within EURO-CORDEX: evaluation of a WRF multi-physics ensemble. Geoscientific Model Development, 8 (3), 603–618. doi: https://doi.org/10.5194/gmd-8-603-2015

[12] Shakirov, V. A., Artemyev, A. Y. (2014). Technique for considering the influence of cloudiness on the solar radiation flux according to the archives of meteorological stations. Systems Methods Technology, 4 (24), 79–83.

[13] Mohamed Fadel' Ali Salem (2010). Zapadnaya Sahara: resursniy potencial i politicheskie realii. Sankt-Peterburg: Roza mira, 107.

[14] Climate impact portal. Available at: https://climate4impact.eu/

[15] Kim, J., Waliser, D. E., Mattmann, C. A., Goodale, C. E., Hart, A. F., Zimdars, P. A. et. al. (2013). Evaluation of the CORDEX-Africa multi-RCM hindcast: systematic model errors. Climate Dynamics, 42 (5-6), 1189–1202. doi: https://doi.org/10.1007/s00382-013-1751-7

[16] Pavlova, T. V., Katcov, V. M., Meleshko, V. P., Shkol'nik, I. M., Govorkova, V. A., Nadezhina, E. D. (2014). New generation of climate models. Proceedings of Voeikov Main Geophisical Observatory, 575, 5–64.

[17] Electronic database of climatic data. Available at: https://ceres-tool.larc.nasa.gov/ord-tool/jsp/EBAFSFC4Selection.jsp

[18] Marzol, M. V., Sánchez, J. L., Yanes, A. (2011). Meteorological patterns and fog water collection in Morocco and the Canary Islands. Erdkunde, 65 (3), 291–303. doi: https://doi.org/10.3112/erdkunde.2011.03.06

[19] Alisov, B. P. (1974). Climatology. Moscow, 300.