



Regional Climate Models Projections of Wind Speed in Morocco for Period 2020-2050

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Moroccan energy system is highly dependent on external energy markets. Therefore, the current renewable energy strategy is focused on deployment of large-scale renewable technology projects. Morocco has abundant wind resources. Estimations made by developing organizations in Morocco which quantify the economic and technical potential of wind energy in Morocco with the amount of 26 GW.

Aims: This study aims to determine the first approximation in the areas of Morocco which are prospective for the development of wind energy in period for 2020-2050.

Place and Duration of Study: Odessa State Environmental University between September 2017 to March 2018.

Methodology: In this particular study the user data from regional climate modeling with a high spatial resolution of the project CORDEX has been estimated. Simulations of local climate models provide opportunities for a better understanding of atmospheric processes in the region and their possible future change. In this study use of regional climate models simulate the RCP of 4.5 scenarios for the Africa region, which is presented in a rectangular coordinate system with a spatial resolution of ≈ 44 km. As a result of the regional climate model calculation, the mean monthly Near-Surface Wind Speed (10-meter Wind Speed) values from 2020-2050 for the territory of Morocco.

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Results: Regional climate models simulations showed that in Morocco will be dominated by gentle and moderate winds, with a mean speed of 4-6 m/s, and only in the southern part of the Atlantic coast its values can reach 7-9 m/s. The smallest values of the mean wind speed are predicted in Fez – Meknes and Beni-Mellal – Henifra regions, and will be about 3 m/s; the highest values can reach 9 m/s on the Atlantic coast to the south of Dakhla village. An analysis showed that in the future some characters of annual course, in general, will have two types.

Conclusion: The most favorable for the development of wind energy will be areas located on the shore of the Mediterranean Sea and the Atlantic Ocean and in the southern part Morocco.

Keywords: Regional climate models; Morocco; wind speed.

1. INTRODUCTION

Today, humanity has come to the understanding that the only realistic way to achieve sustainable development and avoid catastrophic climate change is a rapid and global transition to renewable energy technologies. As a result, the past 2015 United Nations Climate Change Conference, worked out a comprehensive plan with the goal of doubling share renewable energy sources in global energy production by 2030 [1]. The Moroccan energy system is highly dependent on external energy markets. Therefore, the current Moroccan renewable energy strategy is focused on deployment of large-scale renewable technologies projects. Morocco has abundant wind resources. Estimations made by development organizations in Morocco quantify that the economic and technical potential of wind energy in Morocco amount to 26 GW [2]. At the moment, there are several scenarios for the development of renewable energy in Morocco, diverging only in quantitative assessments, all of which are aimed at increasing the generation of green energy, from the full provision of all needs of Moroccan consumers to the possibility of export some of their environmentally friendly electricity to Europe. This study aims to determine in the first approximation the areas of Morocco which are prospective for the development of wind energy in period 2020-2050.

2. MATERIALS AND METHODS

2.1 Study Area

Morocco is located in the northern-east of Africa (Fig. 1), at latitudes from 20° N to 35° N. The country territory has an area of 446550 km². In the north is washed by the Mediterranean Sea, in the west by the Atlantic Ocean, the length of the coastline is 1835 km. Morocco is separated

from Europe by the Strait of Gibraltar. The eastern borders pass inside the continent.

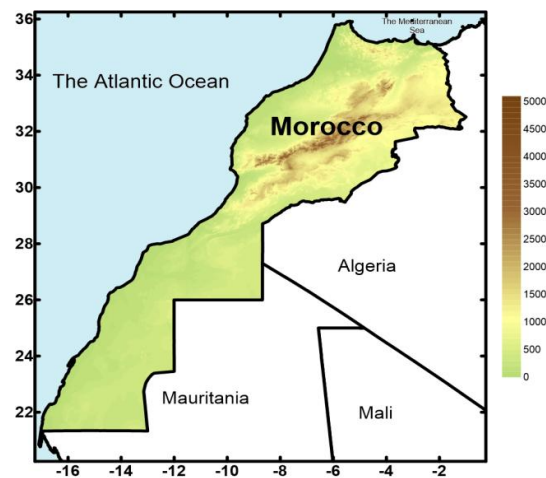


Fig. 1. A map of Morocco

The country territory can be divided into four physico-geographical regions: the Rif (mountainous region) located parallel to the Mediterranean coast, its height does not exceed 1500 m; The Atlas Mountains stretch from the south-west to the north-east and are divided into three main ridges: the Anti-Atlas (2360 m), the High Atlas, whose peaks exceed 3700 m, and the Middle Atlas, the northern part of which is a plateau at 1800 m height; a region of coastal plains lying on the Atlantic coast; the valleys located to the south of the Atlas Mountains, passing into the desert.

2.2 Data Source

The theoretical wind energy potential is estimated with the help of climatic characteristics such as [3]: mean wind speed (per year and by months), the amplitude of the diurnal variation of wind speed for the seasons of the year,

Table 1. Regional climatic 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

distribution (repeatability) of wind speed, vertical profile of mean wind speed, air density, turbulence intensity of the wind flow. In the first approximation, the technical potential can be characterized by a value of the annual wind speed of more 5 m/s at the height of 10 m above the ground [3].

In study used data from regional climate modeling with a high spatial resolution of the project CORDEX [4]. Climate data CORDEX is obtained from the analysis of observational data (1988-2010) or from global climate models (1950-2100). Scaling is performed using several regional climate models, and methods of statistical downscaling. More information about CORDEX-Africa and results of model verification are included to works [5,6]. Simulations of regional climate models (RCMs) provide opportunities for a better understanding of atmospheric processes in the region and their possible future change. The most significant success in reproducing low climatic characteristics compared with observational data give the result of averaging over the ensemble of models. This is because the systematic errors inherent in each model separately are often random concerning the group of models and when averaged over the band, are mutually compensated [7].

In study use of RCMs simulations for RCP 4.5 scenario for Africa region, presented in a rectangular coordinate system with a spatial resolution of ≈ 44 km. For the analysis, an ensemble of 11 climate models developed in research institutes and meteorological centers of various world countries were used. The models used in the study are shown in Table 1. As a

result of the RCMs calculation, the mean monthly Near-Surface Wind Speed (10-meter Wind Speed) values for 2020-2050 for the territory of Morocco were obtained.

3. RESULTS AND DISCUSSION

3.1 The Annual Wind Speed

RCMs simulations showed that in 2020-2050 on the territory of Morocco mainly will be dominated by gentle and moderate winds (Fig. 2a), with a mean speed of 4-6 m/s, and only in the southern part of the Atlantic coast its values can reach 7-9 m/s. The smallest values of the mean wind speed are predicted in Fes - Meknes and Beni Mellal - Khenifra regions, and will be about 3 m/s. The highest values can reach 9 m/s on the Atlantic coast to the south of Dakhla village.

The territory of Morocco may be divided into 4 wind energy zones (Fig. 2b) based on the annual mean wind speed: I zone – up to 4 m/s, II zone – 4-5 m/s, III zone – 5-7 m/s, IV zone – 7 m/s and more. The first zone includes the central areas located in regions of Fes - Meknes and Beni Mellal - Khenifra, and valleys situated to the southeast of the Atlas Mountains near the border with Algeria, placed in the Draa - Tafilalet region. The second zone includes the mountainous areas of the Rif, the Anti-Atlas and the Atlas, part of the coastal plains to the south of Casablanca, and areas adjacent to the border with Algeria and Mauritania in the regions of Guelmim - Oued Noun, Laayoune - Sakia El Hamra, Dakhla - Oued Ed-Dahab. The third zone includes: the Mediterranean coast between Nador and Al-Hoceima; site along coast of the Strait of Gibraltar in the region of Tangier – Tetouan – Al-

Hoceima; part of the Atlantic coast from Safi to Agadir; parts of regions of Guelmim - Oued Noun, Laayoune - Sakia El Hamra, Dakhla - Oued Ed-Dahab. The fourth zone includes part of the Atlantic coast from Tarfaya to the southern border with Mauritania 25-40 km wide. It zone will be the most prospective for development of wind energetics.

3.2 The Monthly Mean Wind Speed

The seasonal variation of wind speed has excellent importance for estimation of the wind potential since it provides essential information about the efficiency of using wind turbines, regarding the consistency of the wind energy supply schedule, with a graph of the energy load of consumers [8]. According [9], in an early 21st century in Morocco, the wind speed has two types of annual course. The first type is found to be an increase in wind speed in the summer and its decrease in period October-February, the second type which is characterized by an increase in wind speed in February-April and a reduction in July-October.

An analysis of RCMs simulations for 2020-2050 showed that in the future a character of annual course, in general, will be preserved and will have such a distribution (Fig. 3): in central mountain regions of Atlas, in the northeastern part of country and on the Mediterranean coast maximum wind speed will be register in winter; summer seasonal maximum of wind speed will be typical on the flat areas of the Atlantic coast, in the southern part of the country and on areas

located behind the ridges of the Atlas mountains on the border with Algeria.

The winter maximum in annual course of wind speed in northern Morocco is due to the shift to the south in winter months of the southern branch of the polar front, which leads to extension into the subtropical zone of the cyclonic type of atmosphere circulation [10]. The reason for the summer maximum wind speed is an increase in pressure gradients on the Atlantic coast as a result of seasonal changes in the pressure field. During the whole year, at a latitude of 30-35°, there is a zone of increased pressure, especially pronounced above the oceans. Over the continents, this zone is preserved only in winter. In summer, due to intense heating, over North Africa, there is a great baric depression [11,12].

3.3 Wind Speed on Different Heights in the Surface Layer

The RCMs calculates wind speeds at 10 m height above the earth's surface, while the axes of modern wind turbines are located at different heights in a layer up to 165 m thick. The technical characteristics of wind turbines directly related to the wind speed that cut-in the speed at which the wind turbine starts to produce some usable power. The rated speed delivers the speed at which the rated power of the wind turbine is reached and the cut-out speed the wind speed which to potentially damage the wind turbine. For most modern wind turbines the cut-in speed is 2.5-5 m/s, the rated speed is 10-15 m/s,

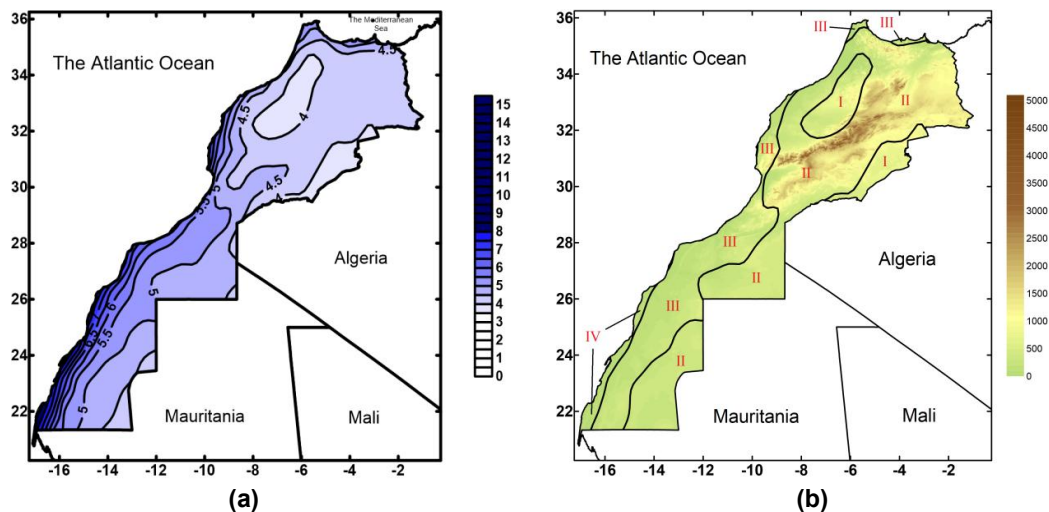


Fig. 2. (a) – Mean wind speed for models of the ensemble (m/s) for period 2020-2050, (b) – Wind energy zones of Morocco

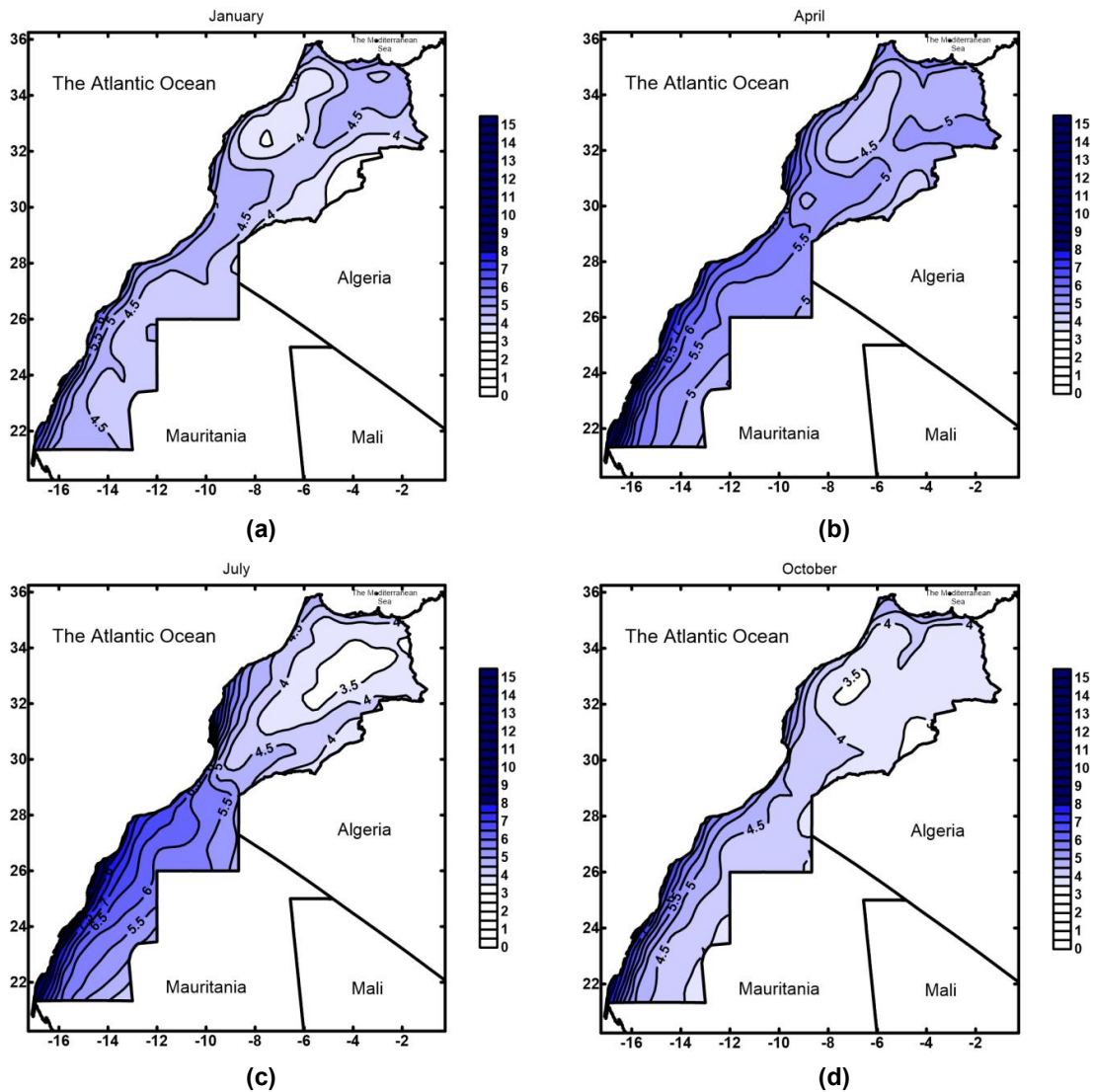


Fig. 3. Monthly mean wind speed (m/s) for period 2020-2050: (a) – January, (b) – April, (c) – July, (d) – October

and the cut-out speed is within 24-25 m/s. All these values refer to wind speed at the height of axis of the wind turbine. In surface layer, the wind speed increases with increasing height above the ground. Therefore, when assessing the wind potential, it is necessary to take into consideration that the wind speed at hub height has higher values. The vertical profile can be described analytically by the power law [3]

$$V_2/V_1 = \left(h_2/h_1 \right)^m \quad (1)$$

Where V_1 – wind speed at height h_1 , V_2 – wind speed at height h_2 , m – variable exponent, which

depending from a season of the year (on average $m = 0.14$ is assumed).

Distribution over the territory of Morocco of wind speeds at heights 50 m, 100 m and 150 m above the ground (Figs. 4-5), calculated with the help of (1). Figure shows that at 50 m height the wind speed increases on 1.25 m/s, at 100 m height on 1.38 m/s and at 150 m height on 1.46 m/s in comparison with wind speed at a height 10 m. In the result, the area which characterized of the availability of wind potential, sufficient for the development of wind power is increased.

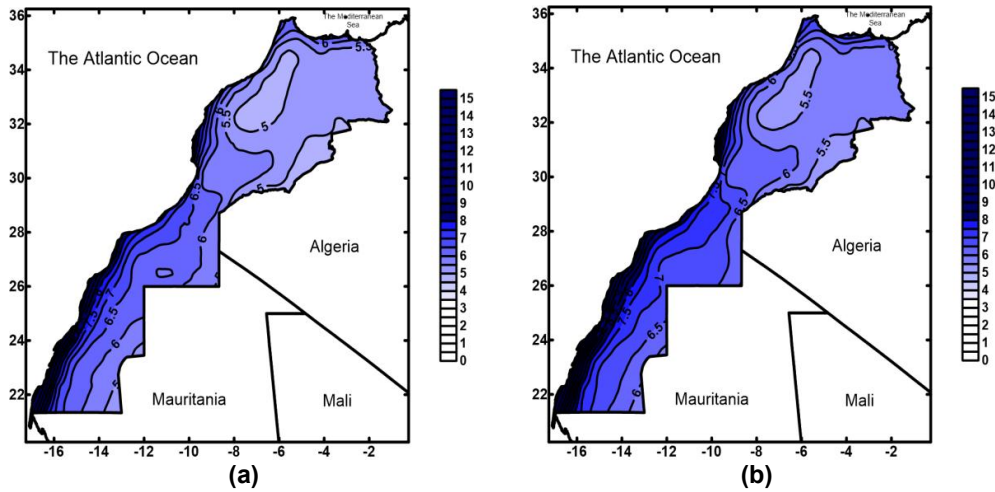


Fig. 4. The mean wind speed (m/s) for period 2020-2050 at height: (a) – 50 m, (b) – 100 m

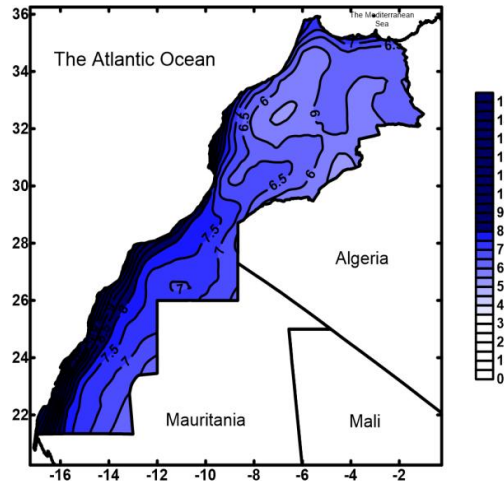


Fig. 5. The mean wind speed (m/s) for period 2020-2050 at height 150 m

4. CONCLUSION

RCMs simulations showed that gentle and moderate winds would dominate the territory of Morocco in 2020-2050.

An analysis showed that in the future an annual course of wind speed would have two types: summer season will have a maximum of wind speed & will be typical on the flat areas of the Atlantic coastland, in the southern part of the country. Whereas, on fields located behind the ridges of the Atlas mountains; in central mountain regions of the Atlas, in the northeastern part of the country and on the Mediterranean coast maximum wind speed will be registered in winter.

The most favorable for the development of wind energy will be areas located on the shore of the Mediterranean Sea, the Atlantic Ocean and in the southern part Morocco.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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