

Regional climate models projections of wind speed in Morocco for period 2020-2050

ABSTRACT

The Moroccan energy system is highly dependent on external energy markets. Therefore, the current renewable energy strategy is focus 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.

Aims: The aim of this study is to determine in the first approximation the areas of Morocco which promising for the development of wind energy in period 2020-2050.

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

Methodology: In study used data from regional climate modeling with a high spatial resolution of the project CORDEX. Simulations of regional climate models provide opportunities for a better understanding of atmospheric processes in the region and their possible future change. In the study use of regional climate models simulations for the RCP 4.5 scenario for the Africa region, presented in a rectangular coordinate system with a spatial resolution of ≈ 44 km. As a result of the regional climate models calculation, the mean monthly Near-Surface Wind Speed (10-meter Wind Speed) values for 2020-2050 for the territory of Morocco were obtained

Results: Regional climate models simulations showed that in Morocco will be dominated by gentle and moderate winds, with an average 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 average 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 a character of annual course in general will have two types.

Conclusion: The most favorable for 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 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 global 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 focus 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 exporting some of their environmentally friendly electricity to Europe. The aim of this study is to determine in the first approximation the areas of Morocco which promising for the development of wind energy in period 2020-2050.

2. MATERIAL AND METHODS

2.1 Study area

Morocco is located in the northern-east of Africa (Fig. 1), at latitude between 20° N to 35° N. The country territory has an area of 446550 km². In the north it is washed by the Mediterranean Sea, in the

34 west by the Atlantic Ocean, the length of the coastline is 1835 km. Morocco is separated from Europe
35 by the Strait of Gibraltar. The eastern borders pass inside the continent.
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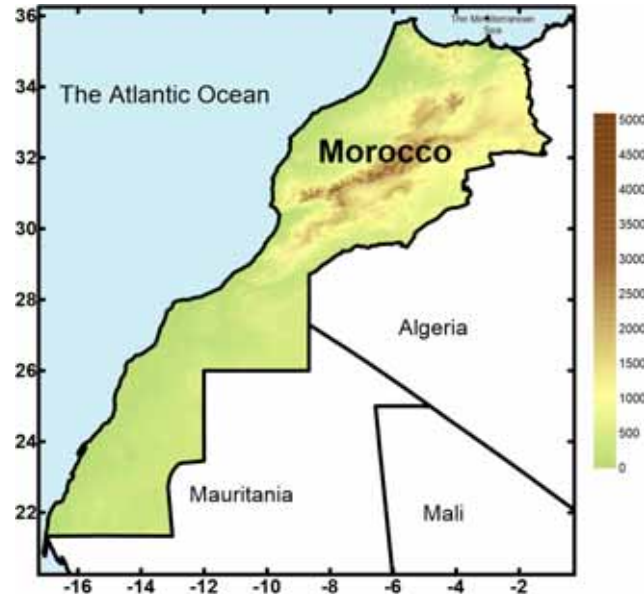


Fig. 1. Map of Morocco

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

48 The climatic characteristics by which the theoretical wind energy potential is estimated are [3]:
49 average wind speed (per year and by months), the amplitude of the diurnal variation of wind speed for
50 the seasons of the year, distribution (repeatability) of wind speed, vertical profile of average wind
51 speed, air density, turbulence intensity of the wind flow. Despite the fact that the average wind speed
52 is an inadequate characteristic for assessing the technical potential, which based on wind power
53 density and wind turbine technology, the initial requirement for the placement of autonomous wind
54 turbines and wind farms (wind power stations) refers to the presence of high wind energy potential. In
55 the first approximation, it can be characterized by a value of the annual wind speed of more 5 m/s at
56 height of 10 m above the ground [3].
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60 In study used data from regional climate modeling with a high spatial resolution of the project
61 CORDEX [4]. Climate data CORDEX are obtained from the analysis of observational data (1988-
62 2010) or from global climate models (1950-2100). Scaling is performed using several regional climate
63 models, and methods of statistical downscaling. More information about CORDEX-Africa and results
64 of model verification are included to works [5, 6]. Simulations of regional climate models (RCMs)
65 provide opportunities for a better understanding of atmospheric processes in the region and their
66 possible future change. The greatest success in reproducing average climatic characteristics
67 compared with observational data give the result of averaging over the ensemble of models. This is
68 due to the fact that the systematic errors inherent in each model separately are often random with
69 respect to the ensemble of models and, when averaged over the ensemble, are mutually
70 compensated [7].
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72 In the study use of RCMs simulations for RCP 4.5 scenario for the Africa region, presented in a
73 rectangular coordinate system with a spatial resolution of ≈ 44 km. For the analysis, an ensemble of
74 11 climate models developed in research institutes and meteorological centers of various world

countries were used. The models used in 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.

Table 1. Regional climatic models characteristics

<i>Nº of model</i>	<i>Model name</i>	<i>The Atmospheric General Circulation Model</i>	<i>Data Centre</i>
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

3. RESULTS AND DISCUSSION

3.1 Annual wind speed

RCMs simulations showed that in 2020-2050 mainly on the territory of Morocco will be dominated by gentle and moderate winds (Fig. 2a), with an average 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 average 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.

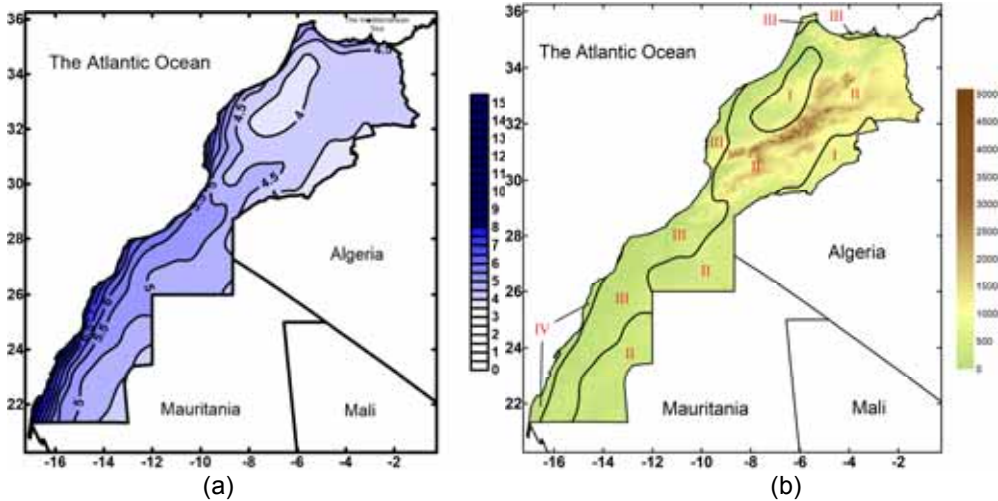


Fig. 2. (a) – Ensemble model average wind speed (m/s) for period 2020-2050, (b) – Wind energy zones of Morocco

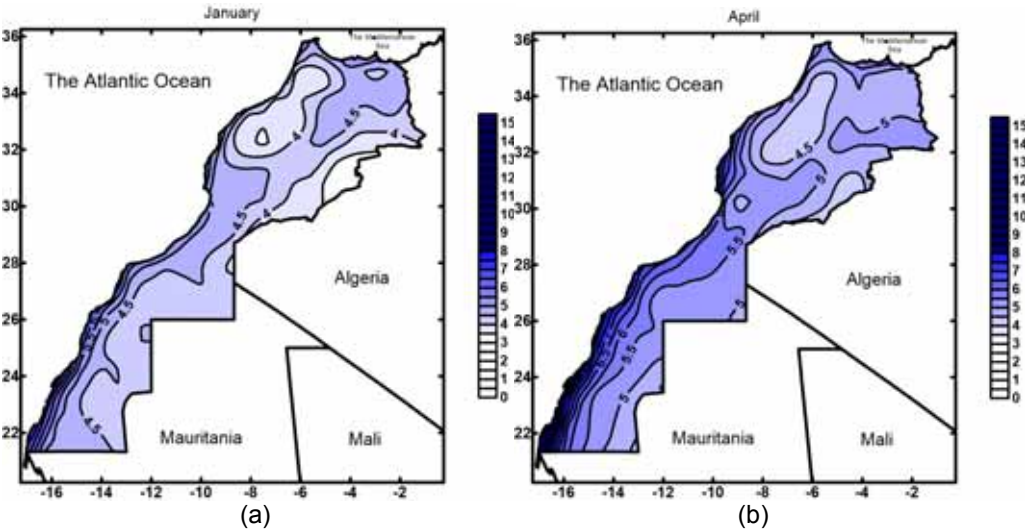
The territory of Morocco may be divided into 4 wind energy zones (Fig. 2b) based on the average annual wind speed: I zone – up to 4 m/s, II zone – 4-5 m/s, III zone – 5-7 m/s, IV zone – 7 m/s and more. The first zone includes the central areas located in regions of Fes - Meknes and Beni Mellal - Khenifra, and valleys situated to the southeast of the Atlas Mountains near 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 contains the Mediterranean coast between Nador and Al-Hoceima, the territory along coast of the Strait of Gibraltar in the region of Tangier – Tetouan – Al-Hoceima, part of the Atlantic coast from Safi to Agadir, and parts of regions of Guelmim - Oued Noun, Laayoune - Sakia El Hamra, Dakhla - Oued Ed-Dahab. The most promising, in terms of wind energy, will be the fourth zone, includes a stretch of the Atlantic coast, 25-40 km wide, from Tarfaya to the southern border with Mauritania.

3.2 Monthly average wind speed

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



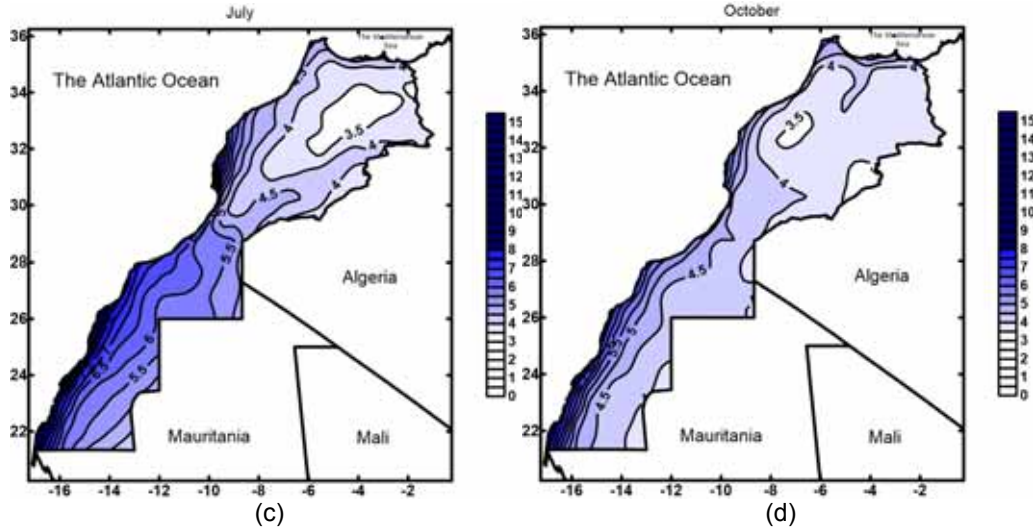


Fig. 3. Monthly average wind speed (m/s) for period 2020-2050: (a) – January, (b) – April, (c) – July, (d) – October

The winter maximum in annual course of wind speed in the northern Morocco is due to the shift to south in winter months of southern branch of the polar front, which leads to extension into subtropical zone of 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 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 the North Africa there is an extensive baric depression [11, 12].

3.3 Wind speed on different heights in 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 is the cut-in speed (the speed at which the wind turbine starts to produce usable power), the rated speed (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 and the cut-out speed is within 24-25 m/s. All these values refer to wind speed at the height of axis of wind turbine. In surface layer, generally, 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 the height of axis of wind turbine has higher values. The vertical profile can be described analytically by the power law [3]

$$\frac{V_2}{V_1} = \left(\frac{h_2}{h_1} \right)^m \quad (1)$$

Where V_1 – wind speed at height h_1 , V_2 – wind speed at height h_2 , m – variable exponent, which depending from season of year (on average $m = 0.14$ is assumed).

A distribution over territory of Morocco of wind speeds at heights 50 m, 100 m and 150 m above the ground (Fig. 4-5), calculated with the help of (1). Figure show what with

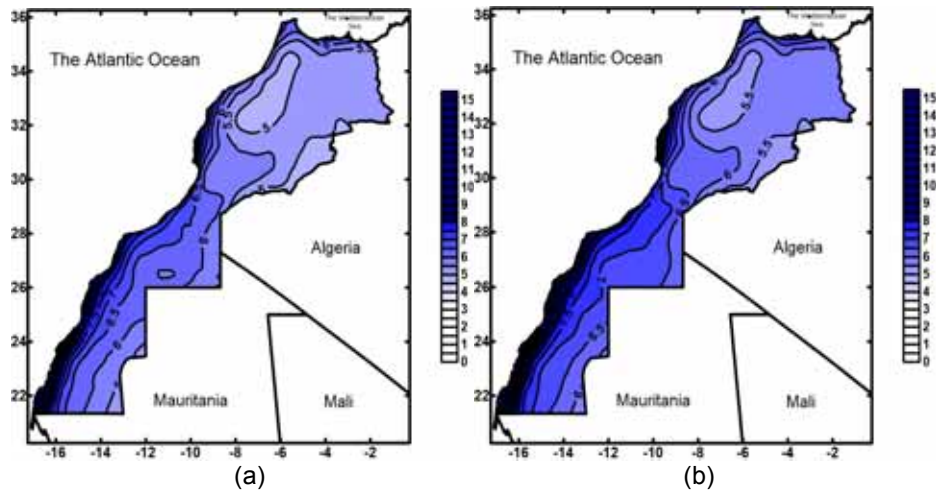


Fig. 4. Average wind speed (m/s) for period 2020-2050 at height: (a) – 50 m, (b) – 100 m above the ground

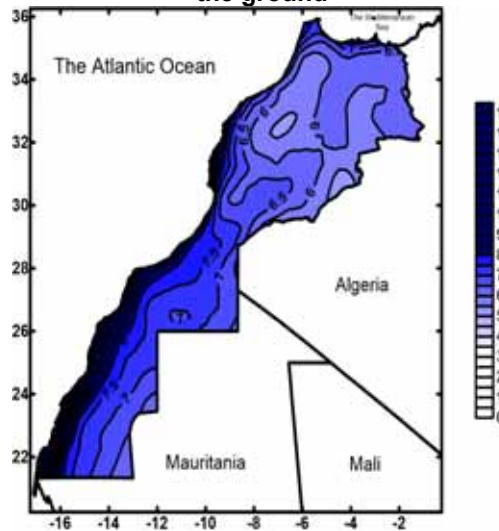


Fig. 5. Average wind speed (m/s) for period 2020-2050 at height 150 m above the ground

an increase in height by 50 m, the wind speed increases on the average by 1.25 m/s, by 100 m by 1.38 m/s and by 150 m by 1.46 m/s. In result the area which characterized of the availability of wind potential, sufficient for the development of wind power is increase.

4. CONCLUSION

RCMs simulations showed that in 2020-2050 mainly on the territory of Morocco will be dominated by gentle and moderate winds.

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

The most favorable for 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.

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