ASSESSMENT OF WIND ENERGY RESOURCE OF MOLDOVA

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1. LEGAL AND INSTITUTIONAL FRAMEWORK IN MOLDOVA'S RENEWABLE ENERGY SECTOR

The energy sector in Moldova faces several problems: strong dependence on the import of natural gas, oil and oil products, outdated technology for the generation and distribution of electricity. According to official statistics in 2012 gross domestic energy consumption amounted to 2145 ktoe, of which 94% was imported. Natural gas is exclusively imported from Russia and is the main fuel for electricity generation and district heating. The electricity produced locally (about 20%) is insufficient and the excess demand is compensated by imports from Transnistria (this territory is not under the control of Moldovan authorities) and Ukraine [1].

Through the Energy Strategy, adopted in 2007 (new version was adopted on February 5, 2013), Moldova has addressed, for the first time in its history, to the use of renewable energy as a viable alternative to compensate the lack of indigenous energy resources. The major piece of primary legislation in the Renewable Energy domain is the Law on Renewable Energy Sources (RES) approved in 2007. Both documents set an ambitious goal: to increase the proportion of RES in the domestic energy mix to 20 % by 2020. The last document in the area of RES - National Renewable Energy Action Plan (NREAP), was approved on 27 December 2013. NREAP is a key document of Moldova's energy policy to promote the use of RES to achieve key strategic objectives of enhancing energy security, long-term development in terms of environmental protection and climate change mitigation. NREAP defines sectorial targets to achieve 20 % of energy from RES by 2020, and establishes legislative action, regulatory and administrative provisions necessary to achieve these objectives [2].

According NREAP, renewable electricity will be produced mainly from wind and by 2020 is necessary about 400 MW wind capacity. At the same time we must answer to the question – does wind potential exist in Moldova? The European Bank for Reconstruction and Development commissioned in 2004 a study concerning the wind potential of the Eastern European Countries, including Moldova. The wind energy potential assessment was based on previous estimates for the USSR in a 1989. According to this study of Moldova's wind technical potential does not exceed 500 MW [3].

In this paper an attempt is made to assess the Moldova's wind energy potential using contemporary software, topographical input data, historical wind data from State Hydrometeorological Service and field measurements conducted during 2002-2003 and 2010-2013 at heights of 30-70 m above the ground level.

2. APPLICABILITY OF THE WIND ATLAS METHOD IN GEOGRAPHY AND CLIMATIC CONDITIONS OF MOLDOVA

2.1. Briefly about the geography and climate of Moldova

Moldova is a republic situated in south-eastern Europe, between two countries: Romania and Ukraine. The area of this small country is about 0,3 percent of the total area of the European space and is 33 844 km2. Moldova belongs to the former Soviet Union. Its independence was proclaimed on August 27, 1991.

The relief of Moldova is a hilly plain, having a slope from northwest to southeast with an average height above sea of 147 m, Figure 1. The northern landscape of Moldova is characterized by gently rolling of the Dniester Hills (up to 300 in elevation) interlaced with small flat plains in the valleys of the numerous creeks (at 150 m). These hills have an average altitude of 240 meters and a maximum altitude of 320 meters. The Central Plateau, at an average elevation of about 350 to 400 m, is interlaced by flat valleys, and scoured depressions. Steep forest-clad slopes account for much of the terrain. There is the country's highest point, Balanesti Hill, which reaches about 425 m. In the south along the left side of the Prut river are situated the Tigheci Hills (average 200 m, maximum 301 m).

Moldova's climate is moderately continental, with some modification of conditions by the Black Sea. The summers are warm and long, with temperatures averaging between 20°C and 25°C, but can sometimes reach 40°C during heat waves. The winters are moderately cold and dry, with daytime January temperatures between -4°C and -7°C, and minima often far below -10°C.

Moldova is influenced by two major climatic factors [4] during the warm season - the Azorean anticyclone, in the cold season - the Siberian anticyclone. Wind regime is formed under the action of two pressure centers stationed over the North Atlantic and Eurasian, and is characterized by the dominance of two contrary wind directions: north - west and south - east. This explains the relatively high proportion of winds from the north - west (25-35 % annually) and from the south - east (15-25 %).

Figure 1. Moldova’s relief.

2.2. Wind Atlas Method: applicability to topography of Moldova

For this study we use the Wind Atlas Method [5] and Wind Atlas Analysis and Application Program (WAsP) [6]. The Wind Atlas Method is developed for various wind applications ranging from wind analysis to siting of wind turbines and calculating power production. It was introduced in 1989 by Risø National Laboratory in Denmark and has since then become an industry standard for wind resource assessments.

The WAsP transforms wind data from existing meteorological masts to describe the wind’s proprieties at specific sites within a radius of up to 100 km.

WAsP contains models for the vertical extrapolation of wind data taking into account sheltering of obstacles, surface roughness changes and terrain height variations. These models are used twice in the process of predicting the wind resource at a site from wind measurements at a different site. At first step, named Wind Atlas analysis model, the regional wind climatology is calculated from a measured time series of wind speed and direction, i.e. wind speed distributions for 12 directional sectors for the geostrophic wind are calculated. It is then assumed that the geostrophic wind climate is representative also for the predicted site. At second step, named Wind Atlas application model, the WAsP are then used to predict the wind resource for the prediction site from the wind climatology calculated in the first step. The output consists of predictions of mean wind speed, wind power density, Weibull wind speed distributions in 12 directional sectors and turbine power output.

Accurate predictions using the WAsP package may be obtained if both sites - the reference and predicted one are:

- subject to the same weather regime, defined by the typical scale of the prevailing synoptic weather systems;
- the prevailing weather conditions are close to being neutrally stable;
- the surrounding topography is not too steep, i.e. sufficiently gentle and smooth to ensure predominantly attached flows and minimal large-scale terrain effect such as channeling.

Next, we consider whether the topography of Moldova meets the conditions of applicability of the WAsP.

The influence of the topography on the accuracy of WAsP predictions was investigated in the papers [7-11]. The authors of these papers have made the following conclusions regarding the limitations and accuracy of WAsP model:

1. The most important factor for the accuracy of WAsP predictions in the steep terrain is the ruggedness of the terrain, described by the ruggedness index (RIX) of the reference and predicted sites. This index must be zero or a few per cent at most. The ruggedness index of a given site is defined as the fractional extent of

the surrounding terrain which is steeper than a critical slope, θC. In our case the critical slope is θC = 0,3. In other words, the slope angle is equal to 17 degrees. The second indicator is ΔRIX, called orographic performance indicator.

2. If one or both of the two indexes is larger than zero, prediction errors must be expected. The orographic performance indicator ΔRIX is defined as the difference in the percent between the predicted and reference sites RIX indexes.
3. If the reference and predicted sites are equally rugged (ΔRIX ~ 0%) the prediction errors are relatively small. If the reference site is rugged and the predicted site less rugged or flat (ΔRIX < 0) the overall prediction is underestimated with a negative error. Conversely, if the reference site is flat or less rugged than a rugged predicted site (ΔRIX > 0), the overall prediction is overestimated with a positive error.

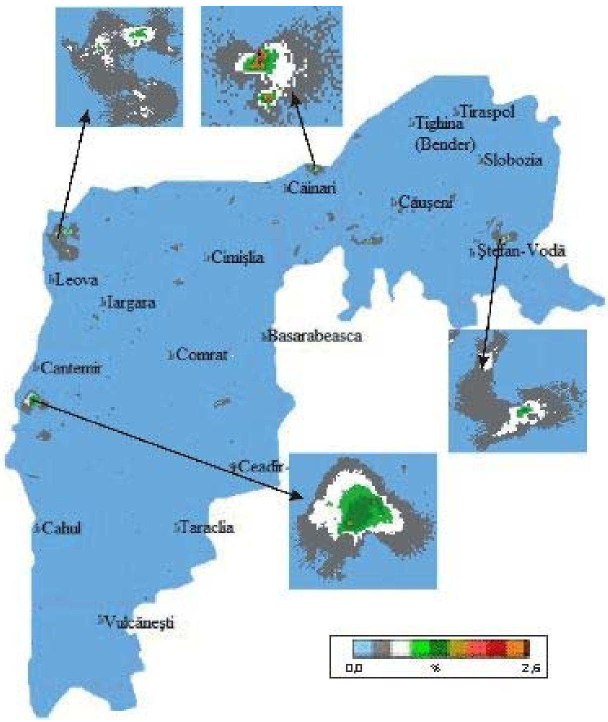


Figure 2. Moldova's south region: ΔRIX map.

4. If the ΔRIX varies between +6,0 and -6,0%, than the wind speed prediction error does not exceed ±5 % [11].
5. Two characteristics of the topographical map are important for the wind speed predictions: the contour line interval and the accuracy of the digitized map [7]. The recommendations are following: prediction errors decrease with decreasing contour line interval-an interval of 20 m or less provide fairly accurate predictions; the prediction errors are large (□ 6%) when grid cell sizes are greater than 100 m.

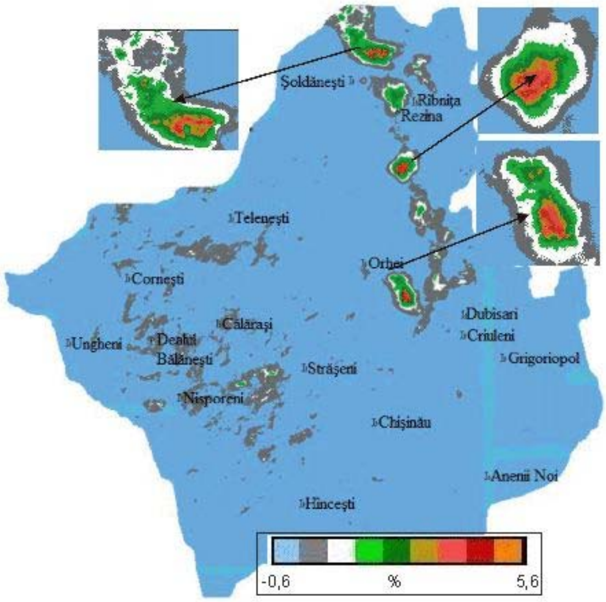


Figure 3. Moldova's central region: ΔRIX map.

In this paper we studied the topographical peculiarities of the economic development regions of Moldova – south, center and north. The aim of the study was to identify if terrain ruggedness and available input topographical data do not exceed the values indicated above.

RIX and ΔRIX values, respectively, for south, central and north economic development regions were calculated. The maximum values of RIX and ΔRIX are presented in the Table 1. We use the map with contour line interval equal to 20 m and grid size of 100×100 m.

Table 1. RIX and ΔRIX maximum values

Region	RIXmax, %	ΔRIXmax, %
South	2,7	2,6
Central	6,2	5,6
North	4,6	4,6

Figures 2-4 show the ΔRIX maps for above mentioned regions and critical areas in which ΔRIX has maximal values. The steepest areas, in which ΔRIX reaches maximum values, are located along the river Dniester (see Figure 3 and 4).

We note that the calculated values of RIX, ΔRIX and the available topographical input data do not exceed those recommended. In other words, topography of Moldova fits the operational envelope of the WAsP model and wind energy potential assessment can be made with an acceptable accuracy. Validation results are provided in the section IV.

3. RESULTS OF THE WIND ENERGY RESOURCES ASSESSMENT

This section presents an overview of the wind energy resources of Moldova in terms of average annual wind speed, wind power density and wind electric potential in terms of installed capacity. For this, the Wind Atlas Method, briefly described in the section B, was used.

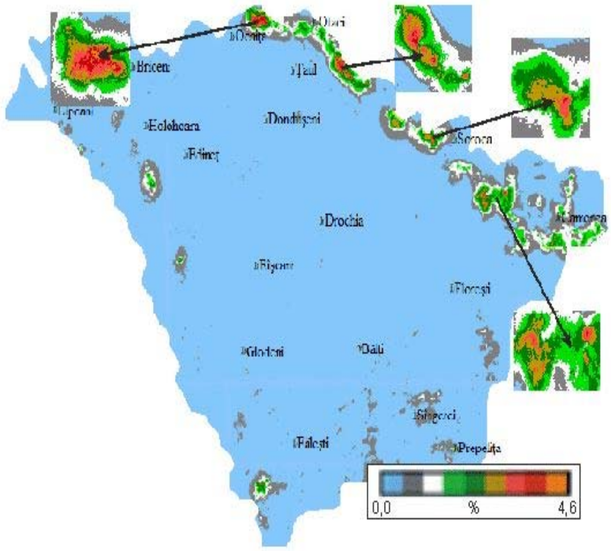
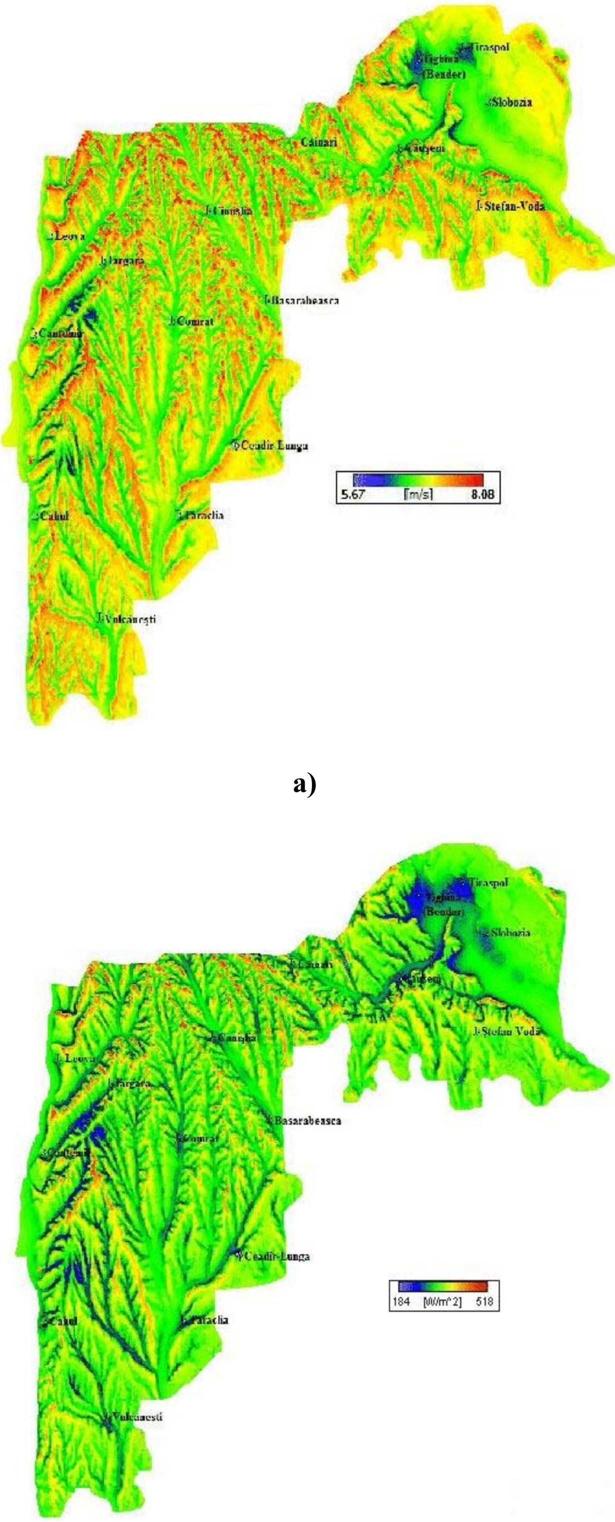


Figure 4. Moldova's north region: ΔRIX map.

Moldova's territory was divided into three regions which coincide with the three development regions - south, center and north. In order to predict wind speed, direction and power density were performed the following steps:

1. For each region a representative meteorological station was selected. In the south this is Ceadir - Lunga station. Regional wind climatology was obtained by using the raw data for an 11 years period. Respectively, for north region – Balti station and raw data for a 10 years period. In the central region all meteorological station are highly sheltered and neither one can't be considered as representative. For the central region were used raw wind data measured in 2010-2013 years period on the highest point of Moldova - Balanesti Hill and conducted by the Technical University of Moldova. Anemometer tower height is 30 m a.g.l.
2. By using WAsP 9.1 software package, the wind maps for two heights – 50 and 100 m a.g.l., were calculated.
3. Using the wind power density map were identified location areas with wind potential greater than 350 W/m^2. If the wind power density of a grid cell was less than 350 W/m2, then the potential was set equal to zero.
4. Next, we calculated the electric wind potential using the assumptions: installed capacity per km^2 is equal to 5 MW.



a)

b)

Figure 5. South region wind energy potential at 100m: *a - wind speed; b - wind power density.*

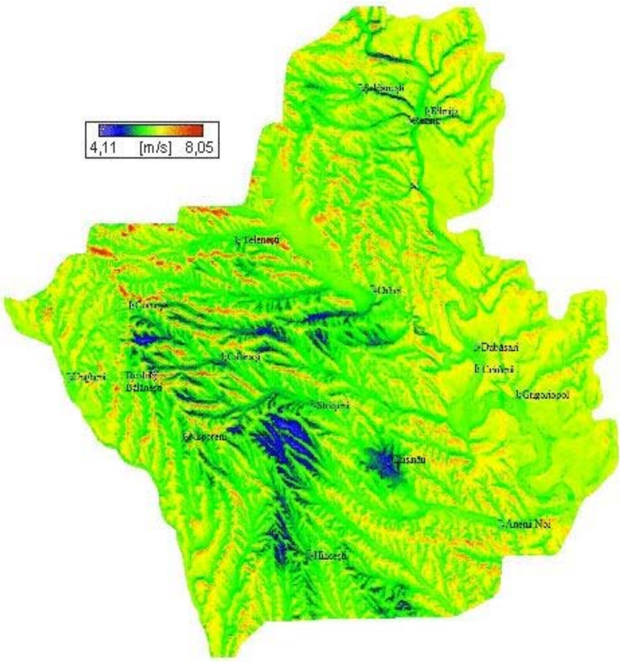
The wind energy potential Maps at a height of 100 m a.g.l. are shown in Figure 5 - 7.

The main obtained outputs are the above presented color-coded maps in units of W/m2 for wind power density and, respectively, in m/s for wind speed. We have classified the Moldova’s wind potential in several classes starting at moderate power density scale of 350-400 W/m^2 and ending with excellent scale with power density of 450-600 W/m^2. The power density and proportion of windy land for each wind resource scale is listed in Table 2. Figures are presented for the three development regions and whole country. Area of the country is equal to 33 844 km^2.

Table 2. Moderate to excellent wind resource at 100 m above ground level.

Wind resource scale	Potential, W/m^2	Land area					
		South		Central		North	
		km^2	%	km^2	%	km^2	%
Moderate	350-400	4456,0	13,2	22,0	0,06	4876,0	14,4
Good	400-450	600,5	1,8	2,7	0,008	1454,0	4,3
Excellent	450-500	13,0	0,04	0,23	0,0007	202,8	0,6
Excellent	500-550	0,1	0,0003	0,0	0,0	28,2	0,08
Excellent	550-600	0,0	0,0	0,0	0,0	4,3	0,01
Total for each region		5069,6	14,1	24,9	0,07	6565,3	19,4
Total for whole country		11659,7 km^2 or 33,6 %					

A special importance for harnessing wind energy has knowledge of the wind power capacity that can be installed in each region. To estimate the wind power capacity we must know the land area with high wind potential and power that can be installed on a unit area, for example, 1 km^2.



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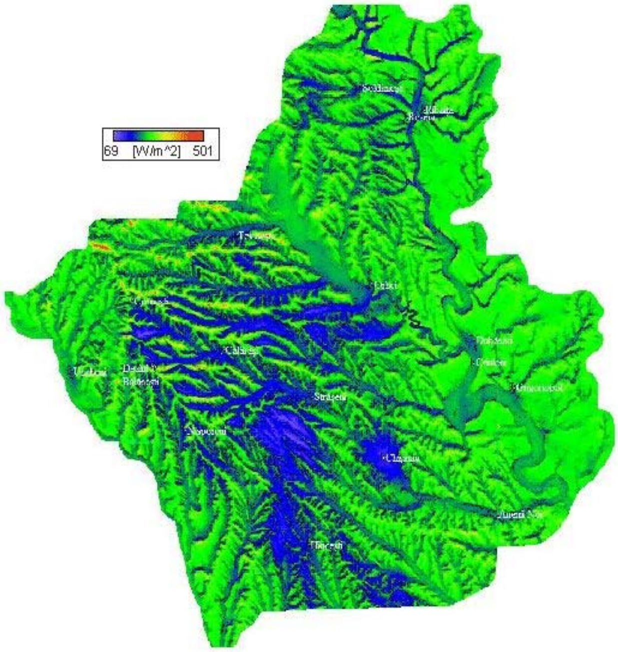


b)

Figure 6. Central region wind energy potential at 100 m: *a - wind speed; b - wind power density*.

Table 3. Moderate to excellent wind power capacity at 100 m above ground level.

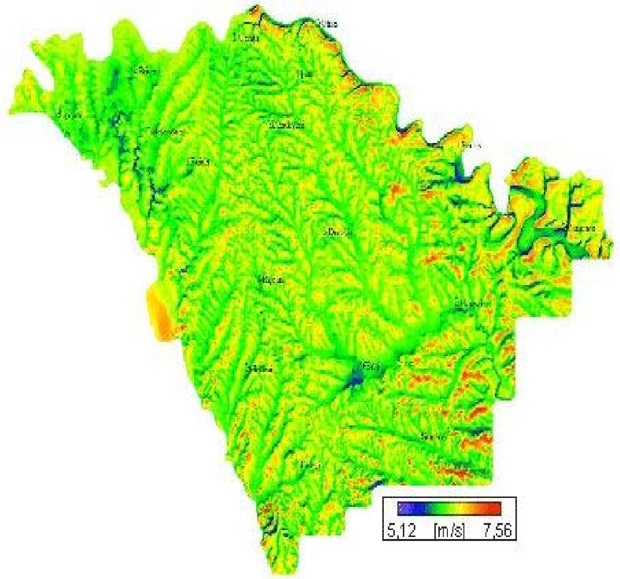
Wind resource scale	Potential, W/m^2	Power capacity, MW		
		South	Central	North
Moderate	350-400	22280	110	24380
Good	400-450	3003	13,5	7270
Excellent	450-500	65	1,0	1015
Excellent	500-550	0,5	0,0	140
Excellent	550-600	0	0,0	21,5
Total for each region		25350	124,5	32827
Country’s total power capacity		58302		

The land areas with high wind potential are listed in Table 2, but concerning the capacity per 1 km^2, there is no common opinion. In various published writings different figures are proposed. Thus, [3] indicates 10 MW/km^2, [12] recommend 5 MW/km^2, [13] and [14] - between 6 and 7 MW/km^2 and [15] - 16 MW/km^2. We accepted a conservative assumption of 5 MW/km^2. The wind power capacity for each resource scale and for each region is listed in Table 3.

The wind resource listed in Table 2 and power capacity listed in Table 3 represents the potential that is not reduced by factors such as land use exclusions: roads, lakes, urban and rural settlements, forests, protected areas, airports and other limitations imposed by the civil and military aviation, electronic communication systems, natural gaz pipelines etc.

4. VALIDATION OF THE RESULTS

European Wind Atlas authors proposed two methods to validate the results of wind resource assessment: meteorological stations intercomparisons and validation against measured wind data at different heights above ground level. [5]. We used the second method. For this, the calculated annual mean wind speed, power density and Weibull coefficients were compared with measured data obtained at the same height. The results are included in the Table 4.



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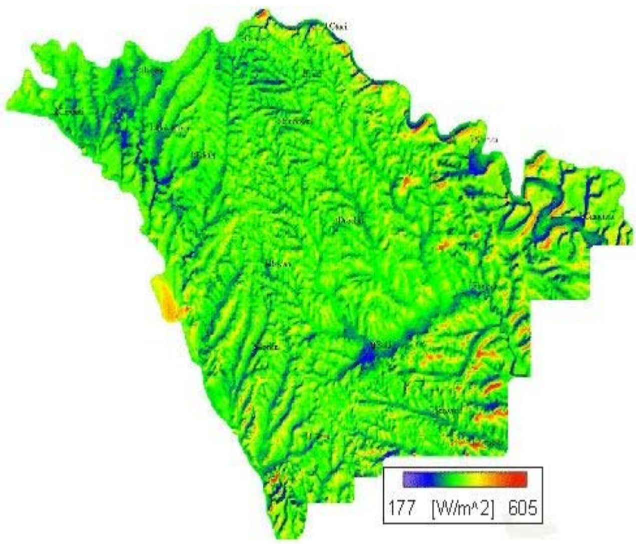

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Figure 7. North region wind energy potential at 100 m: *a - wind speed; b - wind power density.*

The wind speed and power density prediction errors were calculated as $(X_{Calc}/X_{Meas.}-1)100$, there X_{Calc} and $X_{Meas.}$ is, respectively wind speed or power density.

Table 4. Valitation against the measured data different hights.

Region	South		Central		North	
District	Ciadir-Lunga		Hincesti		Donduseni	
Height, a.g.l., m	50		60		75	
Wind speed,	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.
m/s	6,44	6,48	5,82	5,89	6,29	6,11
Wind speed error, %	+0,6		+1,2		-2,9	
Power density, W/m^2	289	277	218	201	241	230
Power density error, %	-4,2		-7,8		-4,6	
A, m/s	6,9	7,3	6,6	6,6	7,1	6,8
K	2,28	2,33	2,11	2,44	2,57	2,61

5. CONCLUSIONS

The topography of Moldova territory meets the conditions of applicability of the WAsP. The maximum value of orographic performance indicator ΔRIX is equal to 5,6 % and corresponds to central region of the country. Wind speed prediction error doesn't exceed 2,9%, respectively, for wind power density – 7,3 %.

The largest areas of windy land are located in the northern and south economic regions, respectively, 19,4% and 14,1% of the total area of the country. The central economic region brings a negligible contribution to the total wind resources. Here the windy land is only 0,07 % of the total area of the country. Causes are: large forested areas, high density of rural and urban settlements. Instead, on the ridges of the hills were identified annual average wind speeds which exceed 8,0 m/s.

At the height of 100 m a.g.l. Moldova's wind energy resources are much higher than the predicted in the former USSR using as input data the measurement results at the height of 10 m a.g.l. About 34 % of the country area has a wind potential between 350 and 600 W/m2. Even, if this area will be reduced by 20 times due to the different constraints, on the remaining area (about 1,7 % from entire country area) can be installed a wind power capacity of 2900 MW. This capacity is about 3 times higher than the current maximum power consumption.

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