Moldova's Wind Power Potential and Levelezed Cost of Energy

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***Abstract* — three aspects concerning wind energy development in Moldova are discussed: (1) the assessment of wind power potential for the height of 100 m above ground level, using a conservative assumption of 5 MW/km^2 and taking into account the main constraints, (2) the identification of a site in the central region of Moldova for building a 40 MW Wind Power Plant and the estimation of annual energy production, (3) levelezed cost of wind electricity assessment.**

Keywords—wind power potential; turbine siting; constraints; annual energy production; LCOE

INTRODUCTION

The first information about the wind energy potential of the Republic of Moldova (RM) in units of electricity is available in EWEA report "Wind Energy-The Facts" published in 2004. The wind potential study of the countries of south-east Europe, including the former Soviet republics, was commissioned by the European Bank for Reconstruction and Development (EBRD) and was based on available data and estimation in former USSR. Wind power technical potential for RM at a height of 50 m above the ground level was estimated at 1,3 TWh/year, which in terms of installed wind power is equivalent to 500 MW, assuming a capacity factor of 30 %.

The conducted research and wind speed measurements at different heights in the recent years, demonstrate that Moldova's wind potential is much higher than mentioned above. In the paper [1] are presented data on wind theoretical potential of the whole country. Thus, 33,6 % of the country area, at the height of 100 m above ground level, has a potential expressed in annual average power density between 350 and 600 W/m^2. Theoretically, if we don't take into account the different constraints, on this area could be installed power capacity estimated at 58300 MW and are much higher than the predicted Moldova's wind potential in the former USSR.

In this paper are discussed three issues: the first is - RM wind power potential, calculated for the height of 100 m above ground level, using a conservative assumption of 5 MW/km^2 and taking into account the main constraints- protected areas, forests and forest belts, urban and rural settlements, roads, rivers, water reservoirs, airports and its easements areas etc.; second issue is to identify a site in the central region of Moldova to build a 40 MW Wind Power Plant (WPP) and to estimate annual energy production; third issue is to assess the Levelised Cost of Energy (LCOE) of this WPP during the lifetime of the wind turbines which is equal to 20 years.

II. MOLDOVA'S WIND POWER POTENTIAL

Moldova's wind energy resources in terms of wind power density and power potential in terms of installed capacity was estimated by using Wind Atlas Method [2,3].

The country territory was divided into three regions which coincide with the economic development regions - south, centre and north. In order to predict wind power density were performed the following:

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 a 11 years period. Respectively, for north region – Balti station and raw data for a 10 years period were used. In the central region all meteorological stations 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 period on the highest point of Moldova - Balanesti Hill (425 m a.s.l.) 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 were calculated at a height of 100 m a.g.l.

3. Using the wind power density maps were identified location areas with wind potential equal and greater than 400 W/m^2. If the wind power density in the grid cell is less than 400 W/m^2, then the potential in the respective cell is considered equal to zero.

4. Next, we calculated the power wind potential using the conservative assumptions: installed capacity per km^2 is equal to 5 MW.

There are various constraints which decrease the theoretical wind potential. We introduce the concept of technical wind potential, i.e. wind potential available within the country with the most important consideration constraints. In the list of constraints were included all areas where wind power density is equal to or greater than 400 W/m^2, but use of these, for some reason, can't be achieved. In other words, at this stage of wind project development in Moldova, we take into account only areas with good and excellent potential (400-600 W/m^2) and not subject of some constraints. The subsequent analysis was excluded the following areas:

1. State protected areas.
2. Scientific reserve "Plaiul fagului", "Iagorlic", " Prutul de Jos", "Padurea Domneasca", "Codrii".
3. National parks.
4. Natural monuments, nature reserves, landscape reserves, resource reserves.
5. Monuments of landscape architecture.
6. Airports and its easement areas – 5 airports: Chisinau, Tiraspol, Marculesti, Balti and Cahul.
7. Rural and urban settlements.
8. Ponds, lakes and rivers.
9. Forests and forest belts.
10. National roads.

Also, we taken into account the rules concerning suitable areas for wind turbines, which say that turbines can be placed at a distance not less than 200 m from the forest or forest belts and 500 m from the rural and urban settlements [4]. In this context, all forests and forest belts, rural and urban areas were excluded with their surrounding areas.

To calculate the wind power potential in terms of installed capacity we use online database of the INGEOCAD Institute and MapInfo software, which in addition is allowing us to find the coordinates for each constraining element it allows to calculate and respective surface area.

The country territory classification as function of average annual wind power density and wind power potential with constraints are listed in table 1 and 2. Figures are presented for the three development regions and whole country.

TABLE 1. COUNTRY TERRITORY CLASSIFICATION WITH CONSTRAINTS AS FUNCTION OF WIND POWER DENSITY

Wind resource scale	Wind power density, W/m^2	Land area					
		South		Central		North	
		km^2	%	km^2	%	km^2	%
Good	400-450	919,5	5,1	748,2	2,72	0,02	2,21
Excellent	450-500	88,0	5,2	42,0	0,26	0,00	0,12
Excellent	500-550	0,1	0,0	19,6	0,00	0,00	0,06
Excellent	550-600	0,0	0,0	2,5	0,00	0,00	0,01
Total for each region		1007,6	10,3	812,3	2,98	0,02	2,4
Total for whole country		1830,2 km^2 or 5,4 %					

If we take into consideration the wind moderate potential (average annual power density 300 W/m^2) and do not take into account constraints, when available area is 34,4% of the whole country territory.

TABLE 2. COUNTRY WIND POWER POTENTIAL WITH CONSTRAINTS

Wind resource scale	Potential, W/m^2	Power capacity, MW		
		South	Central	North
Good	400-450	4597,5	25,5	3741,0
Excellent	450-500	440,0	26,0	210,0
Excellent	500-550	0,5	0	98
Excellent	550-600	0	0	12,5
Total for each region		5038	51,5	4061,5
Country's total power capacity		9151,0		

III. ANNUAL ENERGY PRODUCTION OF 40 MW WIND POWER PLANT

A. Site identification for wind power plant

When looking for a good site for WPP many different factors have to be considered. The most important is, of course, the wind resource. In our case site identification for WPP is simplified due to the access to wind resource maps published in [1]. In fig. 1 is presented annual mean wind speed map in the central region of Moldova. 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. We selected a hill with a height 350-380 m a.s.l. located between the villages Sipoteni Valcinet. The available hill area for the placement of the turbines has dimensions about 500x5000 m, thus, the turbines can be placed only along the hill.

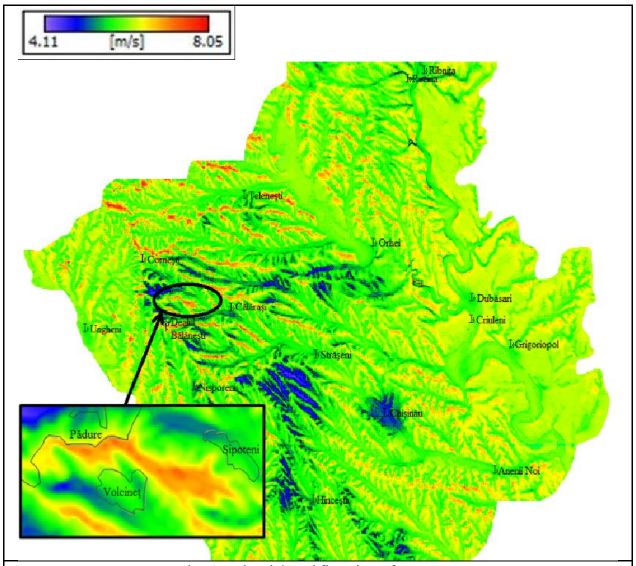

Fig.1. Site identification for WPP

With consideration of recommendations concerning wind turbine siting, described in [4], was carried out siting of 20 wind turbines type V90 - 2.0 MW GridStreamer ™. In fig. 2 are presented all turbines and wind rose. We find that the prevailing wind direction in the site is approximately perpendicular to the turbines row. In this case a turbine influence over another will be minimal and wake losses will be lower. The main technical data of the turbine V90 - 2.0:

1. Rated power – 2000 kW.
2. Cut-in wind speed – 4 m/s.
3. Rated wind speed – 12 m/s.
4. Cut-out wind speed – 25 m/s.
5. Wind class – IEC IIIA.
6. Rotor diameter – 90 m.
7. Blade length – 44 m.
8. Hub height – 105 m.
9. Generator type – permanent magnet generator and fill scale converter.

An important characteristic of this turbine is that it meets the most advanced grid requirements.

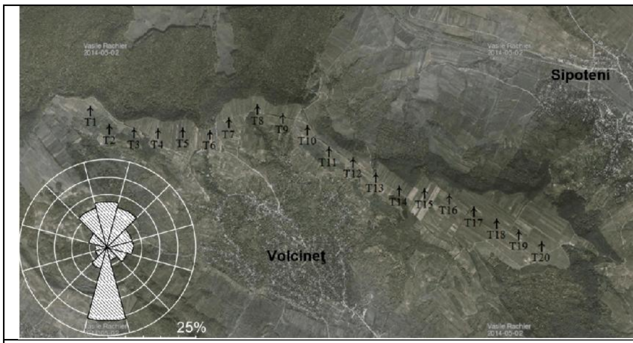

Fig.2. Wind turbines siting: INGEOCAD image.

B. The site wind potential and WPP annual average energy production

To calculate the wind potential of the selected site and the average annual energy production (AEP) we used the software package WAsP 9.1 and the following input data:

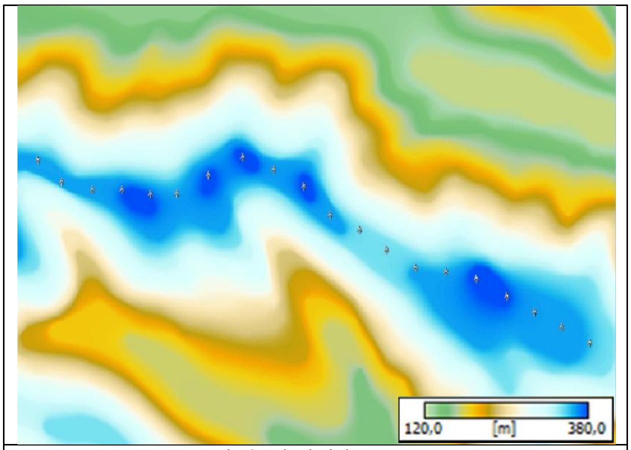

Fig.3. The heights map.

- Digital orographic map with contour line interval equal to 20 m;
- Wind turbines coordinates according siting in fig. 2;
- Wind Atlas of the reference meteorological station. It is Balanesti Hill at distance about 8 km from selected site, anemometer height – 30 m;
- Wind turbine power characteristic P*(V)*. It is provided by the constructor;
- Hub height - 105 m a.g.l.;
- Wind recourses map resolution – 25x25 m.

The calculated wind resources map and AEP map are shown in figures 3-5.

Also, for each turbine were calculated: average annual wind speed, gross AEP, net AEP and wake losses. These figures are presented in table 3.

Total WPP annual gross energy production is 119,056 GWh, average wake loss -2,4 %. This figure does not include WPP losses in the electrical grid, transformers, etc. and the availability factor of the turbine. According to [5] the total losses ranging from 10 to 15 %, we accept 12,5 % and the net AEP will be 104,174 GWh. This figure will be used for levelized cost of energy calculation.

IV. Levelesed Cost of Wind Electrisity

The method of levelized costs of electricity (LCOE) is one of the utility industry's primary metrics for the cost of electricity produced by a generator. It is calculated by accounting all of a system's expected lifetime costs including construction, financing, fuel, maintenance, taxes, insurance and incentives, which are then divided by

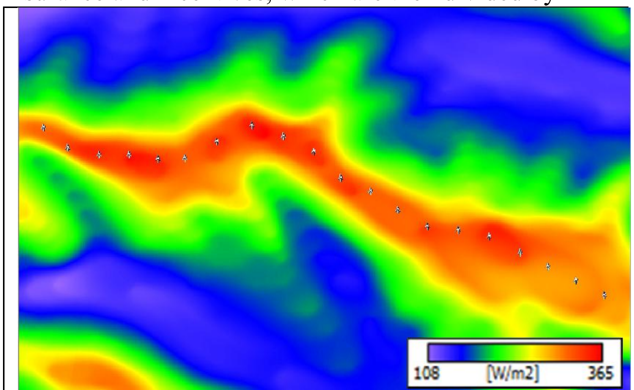

Fig.4. The power density map.

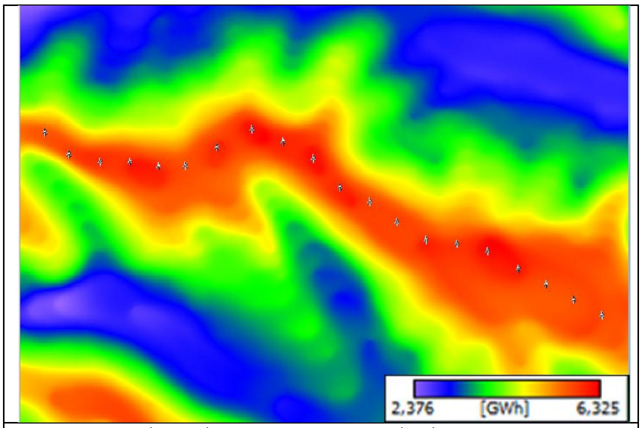

Fig.5. The average energy production map.

TABLE 3. CALCULATED RESULTS FOR EACH TURBINE

Turbine #	Elevation, m	Speed, m/s	Gross AEP, GWh	Wake losses, %
T1	360,0	6,8	5,683	1,90
T2	360,0	6,8	5,674	2,75
T3	361,0	6,9	5,951	2,15
T4	380,0	7,1	6,177	2,27
T5	380,0	7,0	6,085	2,53
T6	362,0	6,8	5,750	2,35
T7	380,0	7,0	6,030	2,31
T8	380,0	7,1	6,230	1,96
T9	363,0	7,0	6,064	2,33
T10	380,0	7,1	6,215	2,53
T11	361,0	7,0	6,041	2,57
T12	342,0	6,9	5,833	2,07
T13	341,0	6,8	5,810	2,25
T14	360,0	7,0	6,070	2,46
T15	360,0	6,9	5,940	2,41
T16	380,0	7,1	6,206	2,37
T17	380,0	7,0	6,135	2,65
T18	361,0	6,8	5,703	3,12
T19	360,0	6,8	5,691	3,11
T20	353,0	6,8	5,768	1,88

the system's lifetime expected power output. All cost and benefit estimates are discounted to account for the time-value of money. LCOE makes it possible to compare the cost of energy produced by any power plants, inclusively using the different technologies for renewable energy conversion [6]. In this paper we used LCOE calculation method described in [7].

LCOE calculation formula is

$$LCOE = \frac{DTC}{DTE}, \qquad (1)$$

where *DTC* is discounted total costs during the study period; *DTE* - discounted total amount of electricity produced during the lifetime of the wind turbine, we accept $T = 20$ years.

If we produce the wind power discounted total costs will be as

$$DTC = DTC_I + DTC_{O\&M}, \qquad (2)$$

where DTC_I is discounted investment total costs; $DTC_{O\&M}$ – discounted operating and maintenance (O&M) total costs.

The discounted investment total costs is

$$DTC_I = \sum_{t=-(d-1)}^{0} I_t (1+i)^{\theta - t}, \qquad (3)$$

where I_t - is the investment made in the construction of wind power plant (WPP) in year t; θ – year in which we discounted. As a rule the construction period for WPP is one year and discounted should be done for $t = 0$ and $\theta = 0$. In this case

$$DTC_I = i_{sp} \cdot P_n \cdot N_{TE}, \tag{4}$$

where i_{sp} is specific investment, €/kW; P_n – wind turbine rated power; N_{TE} - number of wind turbines.

Assuming i_{sp} = 1500 €/kW, P_n = 2000 kW, N_{TE} = 20,

$DTC_I = 1500 \cdot 2000 \cdot 20 = 60 \cdot 10^6$ €.

O&M costs are variable – in the first year of operation are small then from year to year increases. We assume that O&M costs increase as a power function with annual rate $r_{O\&M}$

$$C_{O\&M,t} = C_{sp,1}\left(1 + r_{O\&M}\right)^t, \tag{5}$$

where $C_{O\&M,\,t}$ is the variable O&M costs corresponding to year t; $C_{sp,\,1}$ – specific O&M costs for first year; $r_{O\&M}$ - annual growth rate of O & M costs. To calculate the annual growth rate $r_{O\&M}$ we use the results of study provided by Deutsche WindGuard Consulting GmbH and published in [3]. According to this study for the first year specific O&M costs are equal to 5,5 €/MWh/year and for the 20th year increase to 22 €/MWh/year. With this data and using (5) we calculated the annual growth rate $r_{O\&M}$ that is equal to 0,076 or 7,6 %/year.

Discounted O&M total costs are calculated using formula

$$DTC_{O\&M} = C_{O\&M,0} \cdot \overline{T}_{T,X1}, \tag{6}$$

where $C_{O\&M,0}$ are the reference value of annual O & M costs, related to year 0; $\overline{T}_{T,X1}$ is the period calculated for annual rate, $X1$, that takes into account the real discount rate i=12 %, the annual growth rate of O & M, costs, $r_{O\&M}$ and wind turbines exploitation period, T = 20 years:

$$X_1 = \frac{1+i}{1+r_{O\&M}} - 1 = \frac{1+0{,}12}{1+0{,}076} - 1 = 0{,}0409 \quad \text{and}$$

$$\overline{T}_{T,X1} = \frac{1-\left(1+X1\right)^{-T}}{X1} = \frac{1-\left(1+0{,}0409\right)^{-20}}{0{,}0409} = 13{,}5 \text{ years}$$

Specific O&M costs related to year 0, $C_{sp,0} = C_{sp,1}(1+r_{O\&M})^{-1} = 5{,}5(1+0{,}076)^{-1} = 5{,}1$ €/MWh/year and $C_{O\&M,0} = C_{sp,0} \cdot AEP = 5{,}1 \cdot 104{,}2 \cdot 10^3 = 531{,}4 \cdot 10^3$ €, where $AEP = 104{,}2 \cdot 10^3$ MWh/year is the reference value of annual energy production calculated in the section IV.

According (6) $DTC_{O\&M} = 531{,}4 \cdot 10^3 \cdot 13{,}5 = 7{,}17 \cdot 10^6$ €.

Now, we can calculate discounted costs according (2) $DTC = 60 \cdot 10^6 + 7{,}17 \cdot 10^6 = 67{,}17 \cdot 10^6$ €.

The discounted total amount of electricity produced during the lifetime of the wind turbine is calculated as

$DTE = AEP \cdot \overline{T}_{T,i} = 104{,}2 \cdot 10^3 \cdot 7{,}47 = 778{,}4 \cdot 10^3$ MWh,

where $\overline{T}_{T,i}$ is the period calculated for real annual discount rate i = 12 %

$$\overline{T}_{T,i} = \frac{1-\left(1+i\right)^{-T}}{i} = \frac{1-\left(1+0{,}12\right)^{-20}}{0{,}12} = 7{,}47 \text{ years.}$$

Finally, levelized costs of wind electricity will be equal to

$$LCOE = \frac{DTC}{DTE} = \frac{67{,}17 \cdot 10^6}{778{,}4 \cdot 10^3} = 86{,}3 \text{ €/MWh.}$$

For comparison in table 4 are presented specific investment cost for wind energy LCOE in Germany and two countries from the region - Romania and Bulgaria.

TABLE 4. SPECIFIC INVESTMENT & WIND LCOE

Country	Germania [6]	Romania [9]	Bulgaria [9]
i_{sp}, €/kW	1000-1800	1200-1400	1200-1400
LCOE, €/MWh	45-107	75-81	79-80

V. CONCLUSIONS

The Moldova's wind power resources with a good and excellent potential (400-600 W/m^2), expressed in terms of installed capacity, is much higher than the predicted one in 2004 by EBRD and exceeds the maximum power consumption of about 7,5 times. The estimates were carried out with consideration of the main constraints.

In the climatic conditions of the Moldova's central region 40 MW wind power plant will produce annually 104,2 GWh and corresponds to the capacity factor of 0,3.

The LCOE is about 86 €/MWh and does not differ much from LCOE in Germany and countries from our region - Romania and Bulgaria.

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REFERENCES

[1] V. Rachier, I. Sobor, A. Chiciuc, Assessment of Wind Energy Resource of Moldova. Meridian Ingineresc, nr. 2, 2014, p. 23-29. ISSN 1683-853X.

[2] Ib Troen and E. L. Petersen, *European Wind Atlas.* RISO National Laboratory. Roskilde, 1989, 656 p. ISBN 87-550-1482-8.

[3] N. G. Mortensen, L. Landberg, Ib Troen, E. L. Petersen, O. Rathmann and M. Nielsen, *WAsP Utility Programs.* Risø-I-2261(EN). Roskilde, 2004, 54 p.

[4] T. Wizelius, *Developing wind power projects: theory and practice.* London, 2009, 290 p. ISBN: 978-1-84407-262-0.

[5] *The Economics of Wind Energy.* A report by the European Wind Energy Association. March 2009 - 156 p. http://www.ewea.org/fileadmin/files/library/publications/reports/Economics_of_Wind_Energy.pdf

[6] Faunhofer Institut for Solar Energy Systems ISE, *Levelized Cost of Electricity Renewable Energy Technologies Study.* November 2013. Available at www.ise.fraunhofer.de , accessed 15.07.2015

[7] Ghid privind evaluarea economică a proiectelor din domeniul eficienței energetice și energiilor regenerabile / Agenția pentru Eficiență Energetică; executori: Valentin Arion et al.

[8] Axel Albers, *O&M Cost Modeling, Technical Losses and Uncertainties.* EWEC 2009 Marseille, 17-19 March 2009. www.ewea.org/ewec2009/conference/conference-proceedings, accessed 16.07.2015.

[9] *World Energy Perspective: Cost of Energy Technologies,* World Energy Council, 2013.-48 p. ISBN 978 0 94612 130 4