EFFECT OF WIND CONDITIONS OF SITE LOCATIONS OF WIND TURBINE GENERATORS CAUSED ON PROFITABILITY OF THE COMMERCIAL WIND ENERGY PROJECTS

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Hereby the results of operation of two wind energy projects realized on the basis of the wind turbine generators (WTG) of the NORDEX N54 type of the 1.0 MW capacity each, in the localities of Uzhava and Alsunga at the Baltic sea coast of the Republic of Latvia, over the 5-year period are presented. The results were obtained by means of comparison of the wind conditions and basic economic indexes of operation of the WTG's of the considered projects. It demonstrates the effect of wind conditions and distance of the WTG site locations from the coastline caused on the profitability of the commercial wind energy projects.

Keywords: *wind turbine generator, wind conditions, wind speed, annual electric energy production, prime cost of 1 kWh of electric energy*

1. Introduction

The comparison of wind energy projects realized on the basis of the WTG's of the NORDEX N54 type with the tower 60 m high, in the localities of Uzhava [1, 2] and Alsunga (see Fig.1), was carried out by the following parameters:

- wind conditions of the site locations;
- distance of the site locations from the coastline;
- the annual electric energy production;
- the average annual profit gained over the considered period;
- the prime cost of electric energy;
- effect of the distance of site locations from the coastline on the average wind speed as well as the annual energy production.

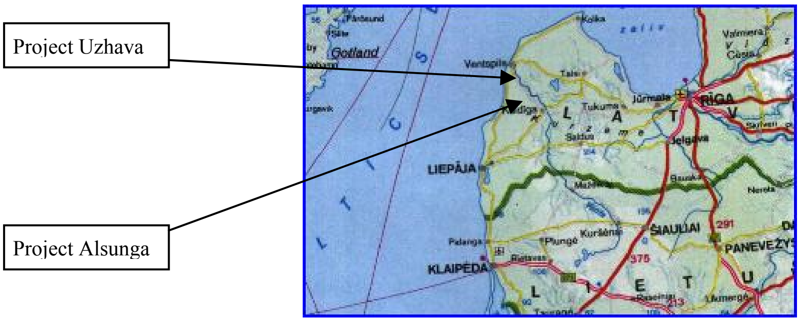


Fig. 1. Map of the Baltic Sea coast indicating the WTG site locations

The exact positions (distance from the coastline) of the WTG site locations shown on the map (Fig. 1) in the observation points make up: 500 m in Uzhava, 13.5 km in Alsunga.

The results below are of practical interest and those can be combined into two different groups: characteristics of wind conditions of the considered region and the basic economic indexes of operation of WTG's. later on these data can be used to estimate the wind energy resources of the considered region as well as when making certain administrative decisions during realization of the commercial wind energy projects, for example, when selecting the optimum site location of WTG.

2. Wind Conditions of the Site Locations

The characteristics of wind conditions below were obtained based on the standard meteorological measurements taken by means of special meteorological stations located at the top part of the WTG gondola.

The further processing of meteorological data stored in the system, which is executed according to the technique described in the work [2], made it possible to obtain the following basic characteristics of wind conditions:

- percentage distribution of wind speeds and calm by months and during the year by different directions;

- recurrence of wind speeds for different directions;
- the average annual wind speed.

The meteorological data regarding wind directions were represented in the form of tables and vector diagrams containing the following wind parameters: the average wind speed to calm ratio by months and different directions.

The comparative characteristics of wind conditions of observation points are presented below.

Table 1 shows the percentage distribution of wind speeds and calm days by directions for the observation point Uzhava.

Table 1. Distribution of wind speed by direction in the locality of Uzhava, (%)

Month/wind direction	N	NE	E	SE	S	SW	W	NW	Calm
I	10	14	11	14	12	14	11	14	2
II	13	9	18	5	12	17	15	11	2
III	12	6	11	14	8	22	15	12	2
IV	3	3	14	22	18	15	15	10	3
V	12	12	7	18	10	13	13	15	3
VI	10	3	5	3	12	26	23	18	3
VII	7	10	10	16	11	16	10	20	4
VIII	6	4	12	14	27	23	8	6	3
IX	7	5	12	2	9	30	26	9	3
X	3	18	7	19	16	11	15	11	1
XI	7	7	9	18	20	24	7	8	2
XII	9	7	17	19	19	11	7	11	1
Year	8	8	11	14	15	19	14	12	2

Following the Table 1, it is obvious that the prevailing wind direction in locality of Uzhava is southwest. Winds of this direction make up 19% during a year. This direction is prevailing (more than 20%) for the four months: September - 30%; June - 26%; November - 24%; March - 22%. The southwest direction also makes up 23% in August. However, it is not prevailing, since the southern direction, which makes up 27%, dominates at this time.

Table 2 shows the percentage distribution of wind speeds and calm days by directions for the observation point Alsunga.

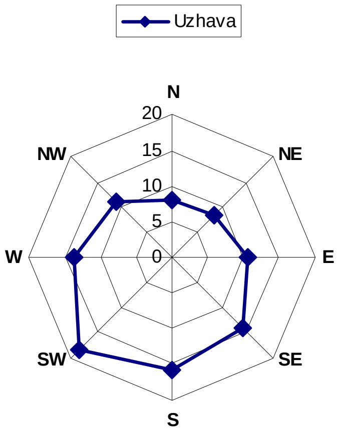
Table 2. Distribution of wind speed by direction in the locality of Alsunga, (%)

Month/wind direction	N	NE	E	SE	S	SW	W	NW	Calm
I	11	7	13	21	11	14	9	14	4
II	14	10	17	30	8	4	4	13	6
III	16	8	7	28	13	5	9	14	7
IV	18	9	17	17	15	10	6	8	5
V	11	8	13	17	19	14	13	5	7
VI	5	8	2	24	12	18	16	15	5
VII	7	8	15	20	15	10	12	13	8
VIII	5	7	15	20	15	12	13	13	7
IX	9	7	15	12	25	18	8	6	7
X	12	10	20	27	13	10	1	7	4
XI	9	10	15	23	20	13	7	3	5
XII	6	10	15	18	21	14	11	5	3
Year	10	9	14	21	16	12	9	10	6

Table 2 shows that the dominating wind direction in the locality of Alsunga is southeast. The amount of this direction makes up 21% during a year. The specified direction prevails for half a year in the following months: February - 30%; March - 28%; October - 27%; June - 24%; November - 23%; January - 21%.

The comparison of data by wind directions as well as the definition of dominating wind direction for the considered observation points can be demonstrated more evidently by means of the vector diagrams (wind rose). When processing the obtained meteorological data regarding the wind direction (Tables 1 and 2) the wind roses were compiled for the site locations of the compared localities. The wind roses show the average wind speed for different directions.

Fig. 2 represents the wind roses for the considered observation points compiled for the heights of the WTG rotor shafts (60 m). The radial lines indicate the length of a part of a year (in percentage terms), during which the wind blows from the given direction.



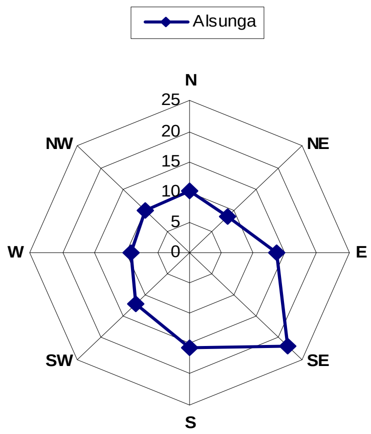


Fig. 2. The wind roses of the compared observation points

The comparison of the wind roses presented in Fig. 2 shows that the dominating wind direction in the locality of Uzhava is southwest. Besides, it is quite obvious that recurrence of western, southern, and southeast wind directions by its frequency is nearing the main direction. The high percentage values (3/4 of the main direction) of these directions make the wind rose for this locality widespread. The prevailing wind direction in the locality of Alsunga is southeast, which has a narrow-pointed rose.

The average wind speed is another major characteristic of wind conditions for the compared observation points. Table 3 shows the data on the average wind speed (by months and during the year) for the height of 60 m, which were obtained according to the technique described in the work [2].

Table 3. The average wind speed in the observation points, m/s

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	Place
V, m/s	7.7	8.0	7.6	6.3	6.4	6.6	6.1	6.4	6.4	7.6	7.3	7.4	7.0	Uzhava
V, m/s	6.0	5.4	5.8	5.7	5.4	5.2	4.8	5.5	5.8	5.7	5.3	6.3	5.6	Alsunga

The comparison of wind data of Table 3 shows that the average wind speed in the locality of Uzhava is 7.0 m/s, which is 25% higher than the value of the average wind speed in the locality of Alsunga (5.6 m/s).

3. The Economic Indexes of the Projects

The following basic economic indexes reflecting the efficiency of commercial wind energy projects were defined:

- the annual electric energy production;
- the average annual profit gained over the period of operation;
- the prime cost of electric energy.

Let us compare the two projects according to the selected parameters.

3.1. The annual electric energy production

Table 4 shows the data on annual energy production (by months, during the year and the average value) for a single WTG of the project Uzhava for the considered 5-year period of operation.

Table 4. The annual electric energy production of WTG of the project Uzhava, kWh

Month \ year	2003	2004	2005	2006	2007	Average
I	256,788	122,048	284,948	183,284	311,612	225,741
II	92,332	178,010	134,528	85,646	189,354	175,303
III	175,766	195,360	137,726	136,724	189,354	185,474
IV	152,666	99,228	145,274	143,439	192,536	131,307
V	105,392	136,574	93,360	161,202	109,092	123,109
VI	128,325	116,722	115,022	93,804	146,990	127,935
VII	69,370	128,656	103,000	76,790	194,870	117,647
VIII	156,382	117,486	158,482	89,680	154,482	127,818
IX	149,988	307,346	161,004	166,134	211,590	164,388
X	163,100	210,176	154,104	222,490	136,742	189,184
XI	107,453	217,900	171,972	222,804	185,360	184,067
XII	296,058	312,192	183,284	413,130	238,760	233,298
Annual	1,853,620	2,141,698	1,842,704	1,995,127	2,196,624	1,985,271

Table 4 shows that the annual energy production by single WTG of the project Uzhava over the considered period fluctuates slightly changing at about 2.0 MWh. Besides, the average amount of the annual energy production makes up 1.99 MWh.

The cumulative data on the annual energy production (by months, during a year and the average value) for the two WTGs of the project Alsunga for the considered 5-year period of operation are presented in Table 5.

Table 5. The annual electric energy production of WTG of the project Alsunga, kWh

Month \ year	2003	2004	2005	2006	2007	Average
I	218,258	155,864	196,884	142,528	386,540	220,015
II	101,278	172,390	177,816	102,360	150,888	140,946
III	183,882	188,994	135,276	132,440	177,714	163,661
IV	209,412	107,814	135,830	138,944	231,458	164,692
V	90,676	169,368	106,378	179,174	99,976	129,114
VI	135,870	111,956	119,272	94,266	74,648	107,202
VII	81,194	111,840	85,734	71,684	157,910	101,672
VIII	179,756	111,648	120,618	111,838	119,898	128,752
IX	128,708	211,848	131,804	148,532	163,680	156,914
X	155,438	178,650	166,154	187,752	123,472	162,293
XI	104,852	156,066	195,438	179,648	175,056	150,057
XII	309,118	268,576	201,094	321,066	225,576	240,707
Annual	1,898,442	1,945,014	1,772,298	1,810,232	2,086,816	1,866,027

Following Table 5, it is obvious that the total annual energy production of the two WTGs of the project Alsunga for the considered period of time also fluctuates slightly changing at about 2.0 MWh. Besides, in this case the average amount of annual energy production makes up 1.87 MWh.

The comparison of data on the electric energy production of both projects (Tables 4 and 5) shows that in spite of the fact that the number of WTGs located in Alsunga is twice higher, both projects have almost identical annual production rate. Hence, the efficiency of wind energy project Uzhava is twice higher as well.

The graphic representation of tabulated data on the electric energy production is shown in Fig. 3, where the curves of the average monthly productivity of WTGs of both projects are shown.

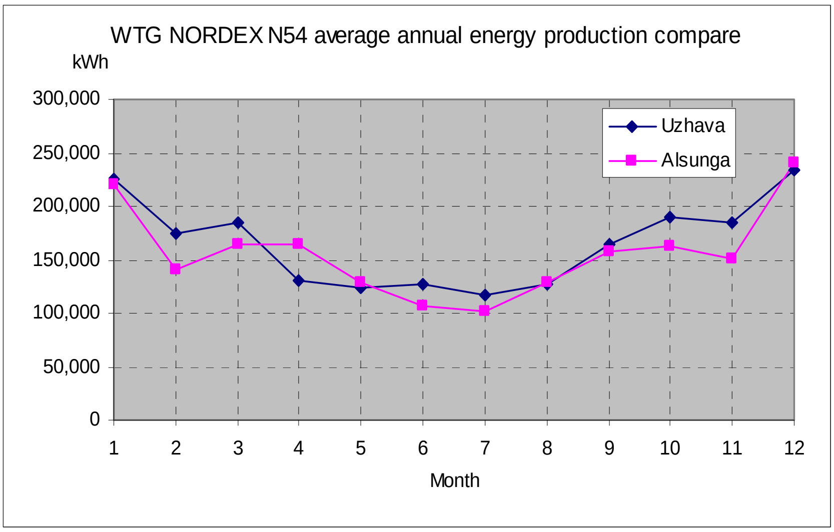


Fig. 3. Comparison of productivity data of the WTG

The curves presented in Fig. 3 allow to better estimate the productivity of both wind energy projects. The comparison of these curves shows that the diagrams of annual electric energy production for both projects are almost identical, which confirms the fact that productivity of the single WTG of the project Uzhava is approximately the same as the total productivity of two WTGs of the project Alsunga.

3.2. The average annual profit gained over the period of operation

The monetary receipts from the sale of electric energy to the network most precisely characterize the profitability of the wind energy projects. The diagram of Fig. 4 shows the average values of sales proceeds by months from realization of the production for both projects.

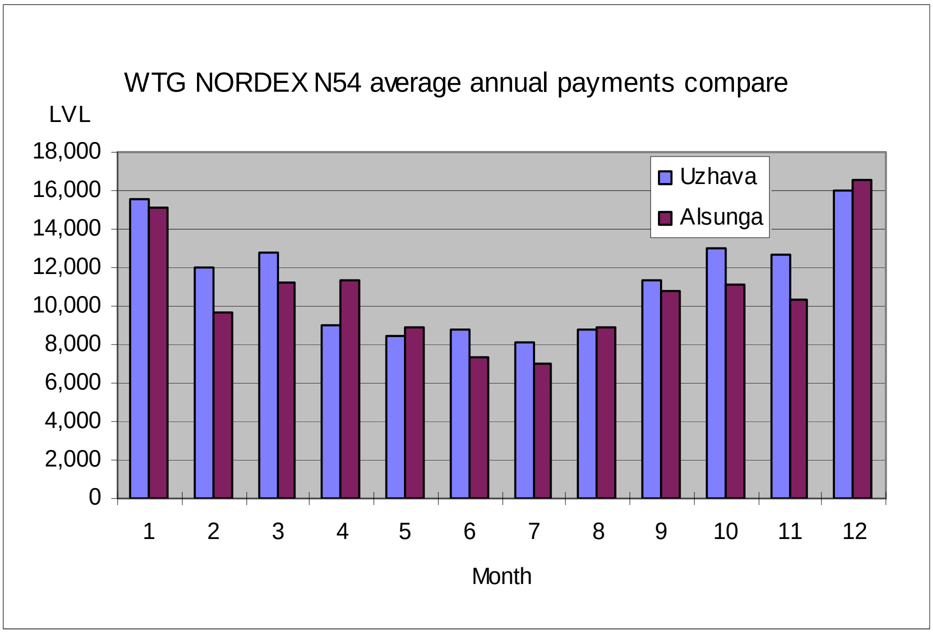


Fig. 4. Comparison of profitability data of the projects

The comparison of data (Fig. 4) shows that the incomes gained from sale of the electric energy of a single WTG of the project Uzhava are approximately the same as those from sale of the electric energy of two WTGs of the project Alsunga. It means that the economic efficiency of the project Uzhava is twice as high.

3.3. The prime cost of electric energy

The major efficiency parameter of the wind energy project is the prime cost of 1 kWh of the electric energy produced by the WTG. In order to assess both projects according to this parameter it is necessary to calculate it first. The calculation of prime cost of the electric energy produced by WTG was made according to the following procedure. At first, the basic operating charges of WTG have been determined.

$$T_{OCH} = P_P + P_{SN} + P_I + P_{TS} + P_{AM} + P_R, \qquad (1)$$

where P_P – salary of the maintenance personnel;
P_{SN} – deductions for the social needs;
P_I – insurance;
P_{TS} – technical maintenance and spare parts;
P_{AM} – administrative and managerial costs;
P_R – the rent.

Then the total prime cost as the sum of: (1), depreciation decrees and credit interests, was calculated.

$$T_{CPP} = T_{OCH} + P_{DD} + P_{PC}, \qquad (2)$$

where P_{DD} – depreciation charges;
P_{PC} – credit interests.

Subsequently, knowing the amount of produced electric energy *E* (data from Tables 4 and 5), the prime cost of 1.0 kWh of electric energy as the ratio of the sum (2) to *E* was calculated.

$$PP = \frac{T_{CPP}}{E}, \qquad (3)$$

The obtained data (1), (2) and (3) were determined for each project for the considered years and tabulated afterwards.

Table 6. Calculation of prime cost of 1 kWh of electric energy of the project Uzhava

No	Index \ Year,	2003	2004	2005	2006	2007
1.	Pay-envelope of auxiliary personnel.	1,440.00	1,440.00	1,440.00	1,440.00	1,440.00
2.	Deductions on social needs.	351.10	351.10	351.10	351.10	351.10
3.	Insurance.	1,333.75	1,333.75	1,983.43	1,333.75	1,983.43
4.	Technical service and awaiting-parts.	1,257.37	1,257.37	6,179.87	1,257.37	6,179.87
5.	Administrative and managerial charges.	20,657.92	10,424.52	20,657.92	20,657.92	20,657.92
6.	Rent.	1,359.00	456.66	1,359.00	1,359.00	1,359.00
7.	TOTAL operating charges:	26,399.14	15,263.40	31,971.32	26,399.14	31,971.32
8.	Depreciation decrees.	64,870.11	71,773.82	64,870.11	64,870.11	64,870.11
9.	Percents on credit-side.	90,426.16	86,682.90	10,426.16	10,426.16	10,426.16
10.	TOTAL complete prime cost:	181,695.41	173,720.12	107,267.59	101,695.41	107,267.59
11.	Electric energy production volume, kWh	1,853,620	2,141,698	1,842,704	1,99,5197	2,196,624
	Prime cost, LVL/kWh:	0.098	0.0811	0.058	0.051	0.049

Table 7. Calculation of prime cost of 1 kWh of electric energy of the project Alsunga

No	Index \ Year,	2003	2004	2005	2006	2007
1.	Pay-envelope of auxiliary personnel.	2,250.00	2,493.33	1,440.00	1,440.00	1,440.00
2.	Deductions on social needs.	542.21	520.44	351.10	351.10	351.10
3.	Insurance.	1,333.75	1,333.75	1,333.75	1,333.75	1,333.75
4.	Technical service and awaiting-parts.	1,257.37	1,257.37	1,257.37	1,257.37	1,257.37
5.	Administrative and managerial charges.	8,197.27	10,876.95	10,424.52	4,956.08	10,424.52
6.	Rent.	456.66	456.66	456.66	456.66	456.66
7.	TOTAL operating charges:	14,037.26	16,938.50	15,263.40	9,794.96	15,263.40
8.	Depreciation decrees.	14,0211.32	72,422.17	71,773.82	71,773.82	71,773.82
9.	Percents on credit-side.	146,729.50	190,531.50	104,180.40	97,779.11	86,682.90
10.	TOTAL complete prime cost:	300,978.08	279,892.17	191,217.62	179,347.89	173,720.12
11.	Electric energy production volume, kWh.	1,898,442	1,945,014	1,772,298	1,810,232	2,086,816
	Prime cost, LVL/kWh:	0.159	0.1439	0.1079	0.0991	0.0832

In order to make it more visual it is better to represent the tabulated data in the form of diagrams (Fig. 5). Fig. 5 shows the data obtained as a result of calculations describing the prime cost of 1 kWh of electric energy for the considered projects.

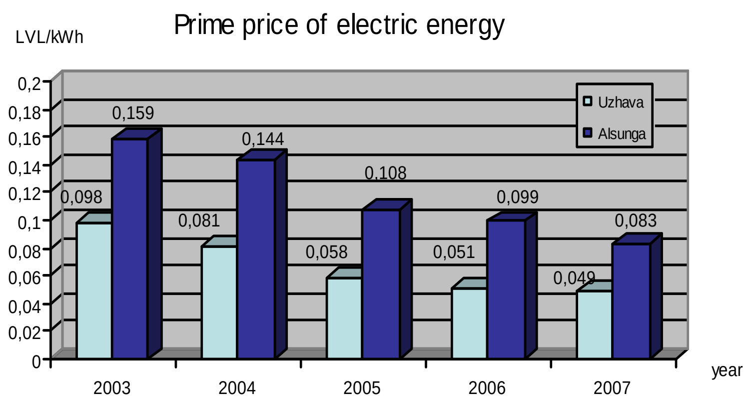


Fig. 5. Comparison of the prime cost of 1 kWh of electric energy produced by the WTG

The comparison of data of the diagrams (Fig. 5) shows that the prime cost of 1 kWh of electric energy of the wind energy project Uzhava is almost twice lower than that of the project Alsunga, which completely corresponds to the data on the profitability of both projects (Fig. 4).

4. Practical Results

The existing relation between the parameters described in the paragraphs 2 and 3 and the distance of the site locations of both projects from the coastline represent some practical interest. Besides, it should be explained how this dependence affects the above-mentioned parameters, and why those have such values. For this purpose, let us make the corresponding calculations and display graphically how the value of the average wind speed as well as the annual electric energy production changes with the increase of the distance of the WTG site location from the coastline for both projects.

The calculations show that the wind speed decreases with the distance from the coastline at a certain attenuation coefficient. Fig. 6 shows the intensity, at which the attenuation of the average wind speed in the observation points takes place with the increase of the distance to the coastline.

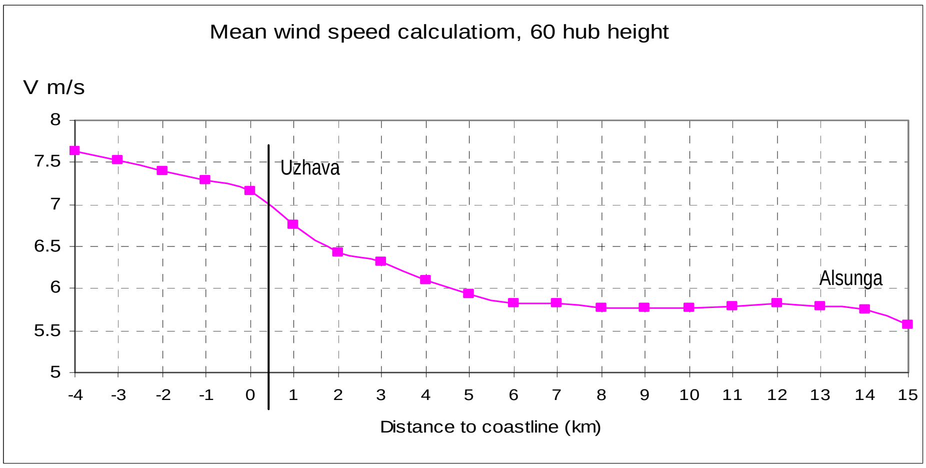


Fig. 6. Change of the average annual wind speed depending on the distance to the coastline

The diagram (Fig. 6) explains why the average annual wind speed in the locality of Uzhava, is equal to 7.0 m/s, in the locality of Alsunga makes up just 5.6 m/s. this happens due to decrease of the wind speed by 1 m/s in the distance of 5 km from the coastline. The attenuation of wind takes place at a certain coefficient, which for the locality of Alsunga is equal to 1.25.

The calculations also show that the annual production rate of WTG decreases with the distance from the coastline. Fig. 7 shows the intensity of decrease of the annual energy production of WTG with the increase of the distance of its site location to the coastline.

The curve (Fig. 7) explains the existing difference in productivity of both projects since it illustrates that the amount of the produced electric energy constantly decreases with the increase of the distance to the coastline. Thus, the reduction already takes place for the first 2 km of the distance, where it makes up the value of 500 thousand kWh; meanwhile by 14 km this value reaches 1000 thousand kWh. All this explains the reasons of lower annual electric energy production of WTG and, therefore, the profitability of project Alsunga.

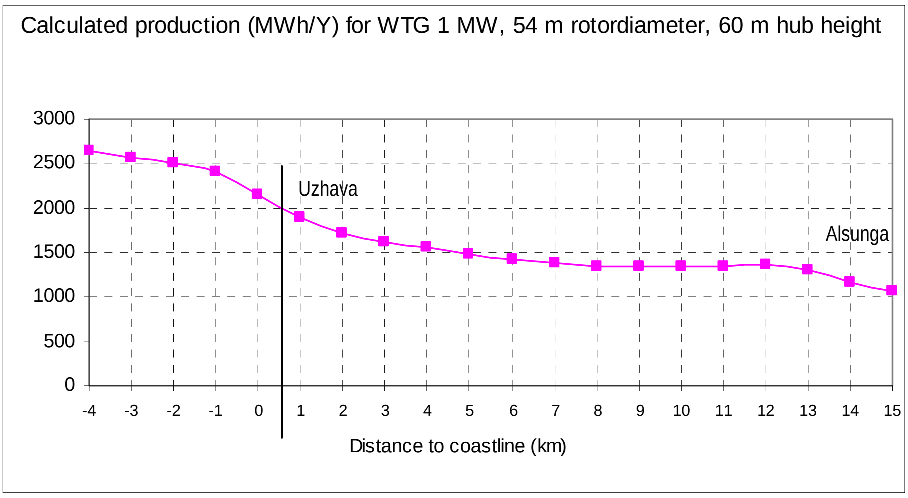


Fig. 7. Change of the electric energy production depending on the distance from the coastline

It is better to estimate the change of annual energy production in relative units. Fig. 8 shows how the percentage reduction of relative productivity of WTG takes place with the increase of distance from the coastline.

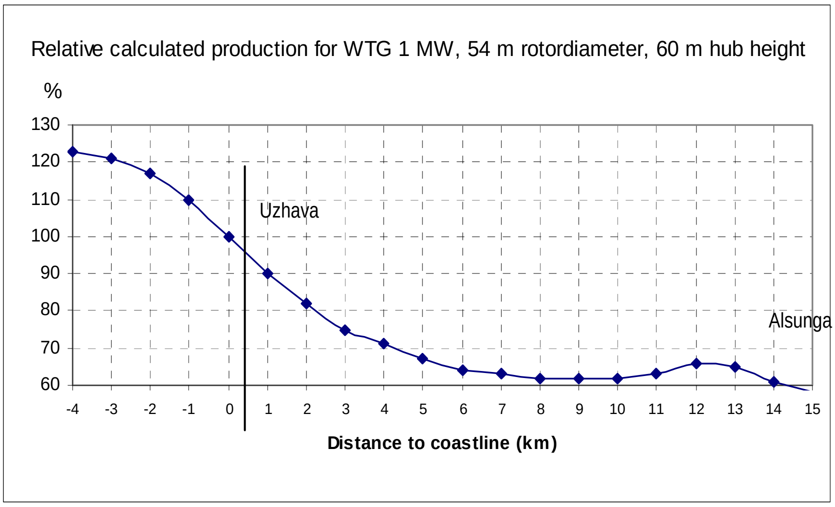


Fig. 8. Change of the relative electric energy production of the WTG depending on the distance from the coastline

The diagram presented in Fig. 8 graphically shows that the value of relative electric energy production drops down by 10% with every kilometer of the distance from the coastline, while for the project Alsunga it makes up only 60% of productivity of the project Uzhava.

Conclusions

1. The prevailing wind direction for the locality of Uzhava is southwest, while for the locality of Alsunga - southeast. Besides, the average wind speed in the locality of Uzhava is 25% higher than in the locality of Alsunga.
2. The annual electric energy production of the wind project Uzhava is twice as high as that of the project Alsunga. Besides, the amount of relative produced electric energy drops down by 10% with every kilometer of the distance from the coastline.
3. The profitability of the project Uzhava is twice higher, while the prime cost of 1 kWh of the produced electric energy is twice lower than that of the project Alsunga.

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