

Research of the variable natural potential of the wind and energy energy in the northern strip of the ukrainian carpathians

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Abstract. The expediency of studying the varying potential of wind and solar energy in the northern strip of the Ukrainian Carpathians is substantiated. The technique of conducting experiments to determine the natural potential of wind and solar energy is proposed and a model for determining the relative volumes of electricity generation by wind farms and solar electrical installations is developed. Based on the conducted research, according to the Drohobych meteorological station, an energy assessment of wind and solar energy resources in the northern strip of the Ukrainian Carpathians was performed. It is substantiated that the theoretical curves of distribution of wind velocity in separate quarters of the year in the territory of the northern strip of the Ukrainian Carpathians are described by the Weibull distributions. Based on the calculations, it is established that the highest total daily solar radiation is in the summer months. Daily graphs of the relative generation of electricity by wind farms and solar electric installations have been constructed. The expediency of formation of combined systems of energy supply of objects from wind and solar energy in the northern strip of the Ukrainian Carpathians has been established. The substantiated patterns of change in the natural potential of wind and solar energy, as well as the graphs of the relative generation of electricity from them, will significantly speed up managerial decisions and improve their quality.

1 Introduction

The relevance of the problem of efficient energy supply of objects from renewable sources of wind and solar energy is confirmed by the fact that individual territories have considerable uneven supply of this energy in different seasons of the calendar year, as well as with respect to their individual species [1-11]. In addition, the creation of energy systems for renewable energy sources and wind to meet consumer needs is a pressing issue, given the recent trends in fossil fuel prices. The peculiarity of creating small energy systems using renewable wind and solar energy is that individual installations do not operate on a single grid, but individually, ie provide electricity to a limited number of consumers. That is why an adequate assessment of their potential is possible if appropriate research is carried out

taking into account specific natural production conditions [12-21].

Conducted scientific studies by Ukrainian and foreign scientists have made it possible to solve many problems of efficient use of non-traditional and renewable energy sources [5-9]. Among these are studies related to the creation of efficient energy systems based on the use of renewable wind and solar energy, operating in deterministic or stochastic conditions [10-11]. At the same time, it has been proved that there is a need to substantiate mathematical models of the changing potential of wind and solar energy in different regions of the world [1-4]. They are at the heart of the modeling and optimization of energy systems for wind and solar energy.

According to this, the substantiation of mathematical models of natural potential and the possibility of wind and sun energy production in the northern lane of the Ukrainian Carpathians has important scientific and practical value.

The purpose of this work is to substantiate mathematical models of natural potential and to simulate the production of wind and solar energy in the northern lane of the Ukrainian Carpathians.

2 Theoretical backgrounds

The energy characteristics of solar and wind resources have a significant impact on the functional performance of renewable energy systems. The analysis of literature sources suggests that to account for the characteristics of solar radiation and wind resources in different energy supply projects, two methods are used: 1) generate retrospective meteorological data for previous years; 2) create models of meteorological conditions. We used the first method of energy estimation of solar radiation and wind energy resources.

To study the random flow, one must be able to estimate the random deviations (fluctuations) of the intensity of the solar radiation and wind. Statistical processing is carried out equally for stationary and non-stationary processes, with the only difference being that the non-stationary flow is investigated not by absolute value but by relative or absolute deviation.

During mathematical processing of a given parameter by experimental (empirical) data, which is limited in number, it is impossible to determine the true values of the distribution characteristics, and therefore determine the so-called estimates of mathematical expectation, variance, root mean square deviation and coefficient of variation. These estimates are called statistical characteristics.

The empirical distributions are consistent with the theoretical criteria specially developed in theory [13]. Arrange the data of the empirical series in ascending order and thus form a variational series:

$$Y_1 < Y_2 < \dots < Y_N. \quad (1)$$

The variational series is divided into k intervals. The number of intervals is determined by the formula:

$$k = 1 + 3,32 \lg N, \quad (2)$$

where N – number of experiments (sample).

The interval interval is calculated by the formula:

$$\Delta Y = \frac{Y_N - Y_1}{k}. \quad (3)$$

The results of the calculations are recorded in Table 1.

Table 1. Results of calculation of statistical characteristics of natural potential of wind and solar energy

№ p/e	Indicator	№ of interval				
		1	2	...	k- 1	k
1	The interval $Y_i^H \dots Y_i^B$	$Y_1^H \dots Y_1^B$	$Y_2^H \dots Y_2^B$...	$Y_{k-1}^H \dots Y_{k-1}^B$	$Y_k^H \dots Y_k^B$
2	The middle of the interval, Y_i	Y_1	Y_2	...	Y_{k-1}	Y_k
3	frequency, m_i	m_1	m_2	...	m_{k-1}	m_k
4	empirical frequency, $P_i = \frac{m_i}{N}$	P_1	P_2	...	P_{k-1}	P_k
5	$Y_i \times P_i$	$Y_1 \times P_1$	$Y_2 \times P_2$...	$Y_{k-1} \times P_{k-1}$	$Y_k \times P_k$
6	$(Y_i - Y_c)^2 \times P_i$	$(Y_1 - Y_c)^2 \times P_1$	$(Y_2 - Y_c)^2 \times P_2$...	$(Y_{k-1} - Y_c)^2 \times P_{k-1}$	$(Y_k - Y_c)^2 \times P_k$

The frequency is then determined m_i by a random variable at each interval, and an empirical frequency is calculated P_i :

$$P_i = \frac{m_i}{N}. \tag{4}$$

The following are the statistical characteristics (estimates):
 mathematical expectation

$$Y_c = \sum_{i=1}^k Y_i \cdot P_i. \tag{5}$$

Dispersion:

$$D = \sum_{i=1}^k (Y_i - Y_c)^2 \cdot P_i. \tag{6}$$

standard deviation:

$$\delta = \sqrt{\sum_{i=1}^k (Y_i - Y_c)^2 \cdot P_i}. \tag{7}$$

coefficient of variation:

$$v = \frac{\delta}{Y_c}; \tag{8}$$

$$v = \frac{\delta}{Y_c - Y_{zm}}. \tag{9}$$

where Y_{zm} – displacement of the scatter zone of random magnitude Y relative to zero.

The estimate of the coefficient of variation according to the formula is calculated if the scatter zone of the exponent Y has a displacement relative to zero. Provided that Y_i of variation series is correct (is included in the sample), it is considered that: $Y_{zm} = Y_1$.

Checking the extreme values of the variation series for their sampling. The first Y_1 and

the last Y_N values of the variance series are needed to be checked for their sample (whether they are correct) according to Irwin's criterion [13]:

$$\lambda_{d1} = \frac{1}{\delta}(Y_2 - Y_1), \tag{10}$$

$$\lambda_{dN} = \frac{1}{\delta}(Y_N - Y_{N-1}). \tag{11}$$

Compare the calculated values with the table values [16] for a given probability ($0,95 < \alpha < 0,99$) and the number of experiments N . If $\lambda_d \leq \lambda_T$, is received, then it is considered that the extreme value is not mistaken. Otherwise, it is removed from the variation series and the calculation of statistical characteristics is repeated.

Check the sample size for normal distribution. With considerable cost and time to perform individual experiments (to determine each value Y) it is important to carry out a quantity sufficient to estimate the statistical characteristics. Mostly the number N_d of experiments for the normal distribution is determined on the basis of ensuring that the relative error (δ) in the estimation of the mathematical expectation with a given confidence probability ($\alpha = 0,8...0,95$) does not exceed 10-20%:

$$N_d = \frac{v^2 t^2}{\delta^2}. \tag{12}$$

where t – quantile of normal distribution.

Compare the calculated value N_d with an actual one and make a conclusion about expediency of carrying out additional experiments.

Construction of a histogram (polygon) of the distribution of the studied indicator and hypothesis about the theoretical pattern of distribution. According to the variation series, plot the relationship between the investigated value and the empirical frequency. For this purpose, the upper, lower and average values of the intervals Y are determined by a certain measure on the abscissa axis. The y-axis defines the empirical frequency.

On the appearance of the histogram, as well as on the value of the coefficient of variation, put forward a hypothesis regarding the theoretical pattern of distribution.

Calculation of theoretical frequency. Calculate the density of the distribution function ($f(Y_i)$) for each partial interval. For Weibull's theoretical distribution, we first need to find the parameters a i b [15].

For each partial interval, the theoretical frequency is calculated:

$$P_n(Y) = f(Y) \cdot \Delta Y, \tag{13}$$

where ΔY – interval step.

Checking the proximity of empirical and theoretical distributions. The proximity between empirical and theoretical distribution is verified by criterion χ^2 [15]. To this end, it is necessary to calculate a product for each partial interval – $N \times P_n$.

Express the criterion by the formula:

$$\chi^2 = \sum_{i=1}^k \frac{(m_i - N \cdot P_n)^2}{N \cdot P_n}, \tag{14}$$

where k – the number of intervals to match them.

Determine the number of degrees of freedom by the formula

$$r = k' - (n + 1), \tag{15}$$

where n – number of parameters of the theoretical distribution function.

By setting the level of significance $\alpha (\alpha = 0,05..0,1)$, we will find for a certain r , value $(\chi^*)^2$ and compare it with the calculated one. If $\chi^2 < (\chi^*)^2$, then the theoretical distribution reflects the empirical data. Otherwise, the proximity between empirical and theoretical distribution is absent.

Production and computer experiments were conducted to achieve the stated purpose and to fulfill the tasks of the work. During the study of the potential of the region and the processes of electricity production from wind and solar energy, the methods of passive production observations, statistical data processing, simulation modeling, etc. were used.

The essence of production experiments is to create an information base on the main characteristics of the design objects and the design environment. Synthesis of theoretical studies and results of production experiments allows us to build the necessary model for estimating electricity production from wind and solar energy.

Determining the distribution of average power consumption of objects and seasonal irregularity is based on the analysis of retrospective data of electricity consumption of enterprises of Stryi district of Lviv region. In order to expand the sample needed to build the trend of seasonality of energy consumption, data from different farms should be normalized - leading to a unit of average monthly energy consumption:

$$w_i (m) = 12 \frac{W_i (m)}{\sum_{n=1}^{12} W_i (n)}, \tag{16}$$

where $W_i (m)$ – actual amount of energy, used by i-household during m-month, kW.h/month;
 $w_i (m)$ – the relative amount of energy.

The fluctuations in the sample statistics can be judged as random deviations from the average load charts.

The main parameter characterizing wind potential is the dynamics of wind speed change. Wind velocity and solar radiation distributions are constructed for each month of the year by processing an array of retrospective data from weather station observation logs.

3 Research results and discussion

Each of the periods of the year for a given region is characterized by the speed of wind flow, on which the choice of type of wind installation depends and the total amount of solar energy that influences the calculation and choice of solar photomodules [5, 9].

Statistical analysis of the obtained data on wind speed in the territory of Stryi district of Lviv region (northern strip of Ukrainian Carpathians) allowed to determine their numerical characteristics and to substantiate theoretical distribution laws, which are Weibull distributions (Fig. 1-4)

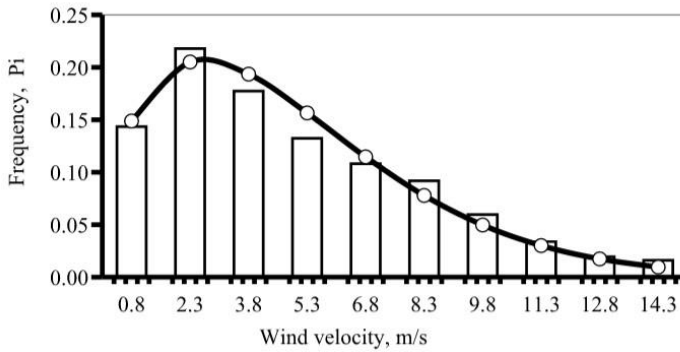


Fig. 1. Wind velocity distribution in the northern lane of the Ukrainian Carpathians (1st quarter). Wind velocity, m/s.

The estimation of the mathematical expectation of wind speed in the territory of a given region for the first quarter is - 4,88m/s, the estimate of the standard deviation - 3,32 m/s., The coefficient of variation - 0,68. (Fig. 1). For the second quarter, the estimation of the mathematical expectation of wind speed on the territory of agricultural enterprises is 4.07 m/s, the estimate of the standard deviation is 3.2 m/s, the coefficient of variation is 0.78. (Fig.2).

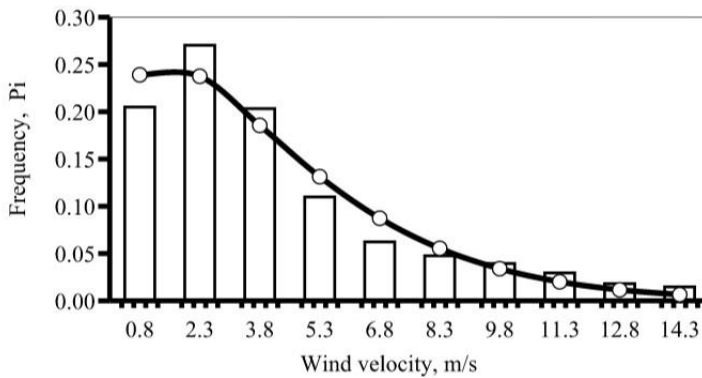


Fig. 2. Wind velocity distribution in the northern strip of the Ukrainian Carpathians (2nd quarter)

For the third quarter, the estimation of the mathematical expectation of wind speed on the territory of agricultural enterprises is 4.09 m/s, the estimate of the standard deviation is 3.13 m/s, the coefficient of variation is 0.76. (Fig.3).

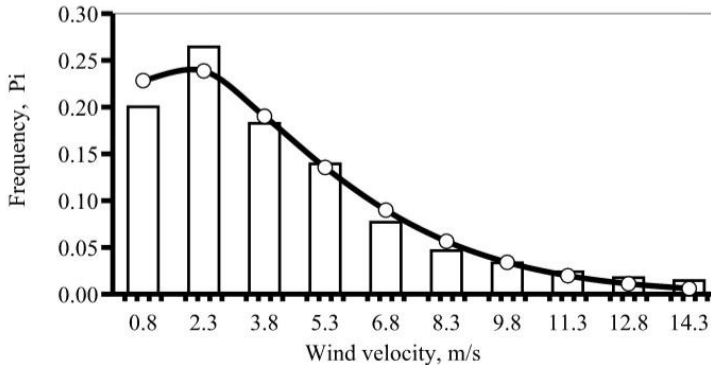


Fig. 3. Wind velocity distribution in the northern strip of the Ukrainian Carpathians (3rd quarter)

For the fourth quarter, the estimation of the mathematical expectation of wind speed on the territory of agricultural enterprises is 4.36 m/s, the estimate of the standard deviation is 3.21 m/s, the coefficient of variation is 0.73. (Fig. 4).

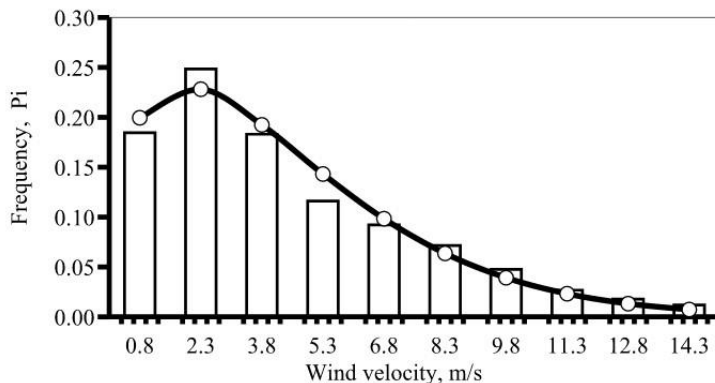


Fig. 4. Wind velocity distribution in the northern strip of the Ukrainian Carpathians (4th quarter)

Similarly, the statistical analysis of the received data on the total solar energy supply in the territory of the northern strip of the Ukrainian Carpathians was carried out, and the results are presented in Table. 2.

Table 2 – Mathematical expectation of total daily solar radiation, cal/cm²

№ p/e	April	May	June	July	August
1	–	–	515,2	480,8	492,5
2	–	406,8	511,2	499,7	489,8
3	–	401,2	460,4	484,2	472,6
4	–	389,4	507,2	488,8	499,1
5	–	451,8	534,1	484,5	451
6	–	473,3	533,2	472,4	407,6
7	–	463,3	533,3	503,2	480,4
8	–	433,7	547,9	488,8	430,5
9	–	453,4	592,4	485,5	465,1
10	–	471,6	510,4	463,1	450,3
11	–	441,4	501,8	527,6	457,1
12	–	431,2	502,9	527,3	405,9
13	–	462,9	499,2	498,1	–
14	–	441,7	535,5	542,7	408,5
15	–	506,1	531,1	517,7	411,5
16	–	495,7	537,3	491,43	389
17	–	474,9	500,3	498,7	405,6
18	362,2	509,2	484,8	537,8	387,3
19	–	525,2	505,8	438,7	375,1
20	–	489,6	554,4	466,6	394,1
21	383,1	506,8	522,2	478,8	–
22	378,1	443,9	547,2	477,6	388,6
23	–	406,6	572,2	468,6	391,1
24	–	453	542,7	516,2	–
25	–	415,5	579,3	485,8	–
26	–	429,6	563,9	442,0	–
27	–	445,9	552,4	458,7	–
28	464,8	474,2	522,4	431,3	368,5
29	452,3	496,7	516,1	497,0	371,2
30	423,9	502,6	489,4	511,4	–
31	–	466,4	–	510,9	397,8
Total :	2833,1	13763,6	16336,2	15175,8	10586,8

Total amount for a year: 55862.4 cal/cm² (2327,6 MJ/m²).

Subsequently, the simulation of electricity production was performed on the basis of the developed simulation model. In modeling the production of energy resources from solar and wind energy, the wind and solar potentials of the northern strip of the Ukrainian Carpathians were taken into account, which made it possible to construct appropriate daily schedules (Fig. 5 and 6).

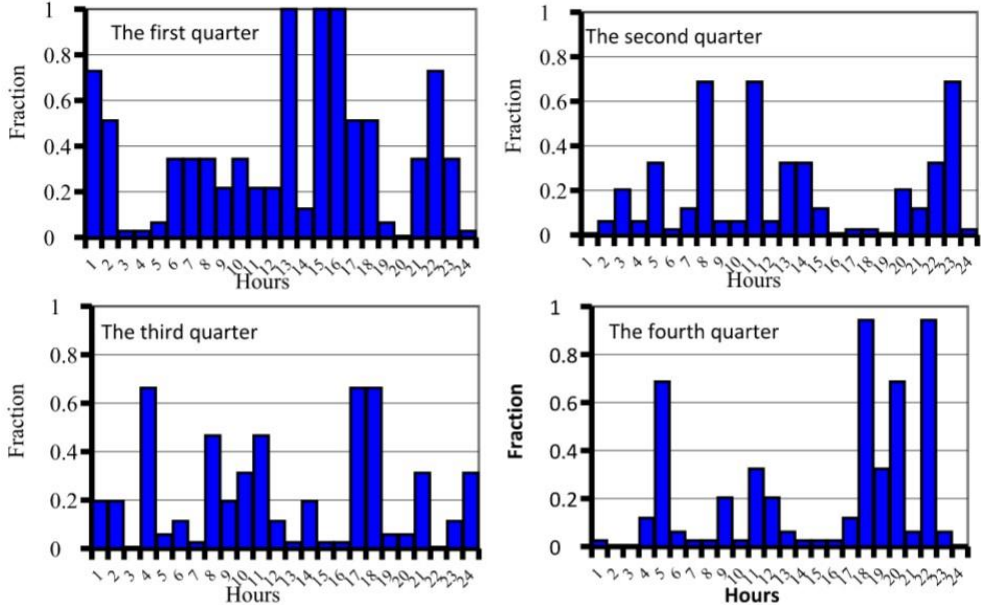


Fig. 5. Daily graphs of the relative generation of electricity by a wind power plant

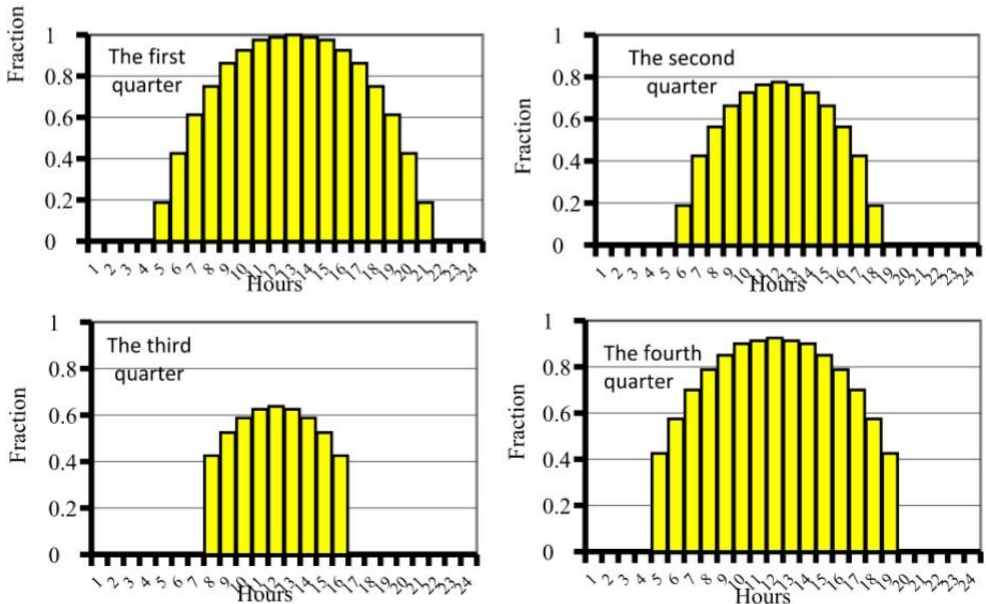


Fig. 6. Daily graphs of the relative generation of electricity from the solar electrical installation

The results show that for the efficient energy supply of objects from wind and sun

energy in the northern strip of the Ukrainian Carpathians, combined systems should be formed. At the same time, their components will be both wind power plants and solar electric collectors, which will replace about 27% of electricity. The conducted research will be useful for the managers of projects of energy supply of objects from wind and solar energy in the northern strip of the Ukrainian Carpathians. They can also be used when designing such systems. The substantiated patterns of change in the natural potential of wind and solar energy, as well as the graphs of the relative generation of electricity from them, will significantly speed up managerial decisions and improve their quality.

4 Conclusion

Based on the conducted research, according to the Drohobych meteorological station, an energy assessment of wind and solar energy resources in the northern strip of the Ukrainian Carpathians was performed. It is substantiated that theoretical curves of distribution of wind speed in separate quarters of the year in the territory of the northern strip of the Ukrainian Carpathians are described by Weibull distributions with mathematical expectation, which fluctuates within 3.21..4.09 m/s.

It is established that the highest amount of total daily solar radiation occurs in the summer months (Table 1). The performed researches made it possible to build daily schedules of relative generation of electricity by wind installations (Fig. 5) and solar electric installations (Fig. 6). Combined systems should be designed to provide efficient energy supply for wind and solar energy in the northern strip of the Ukrainian Carpathians. At the same time, their components will be both wind power plants and solar electric collectors, which will replace about 27% of electricity

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