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## ACCOUNTING THE FACTOR OF RANDOMITY OF SOCIAL PROCESSES IN PREDICTION OF DEMAND FOR ELECTRIC ENERGY

**Purpose.** Taking into account the factor of randomness of social processes when forecasting the demand for electric energy to reduce the error.

**Methodology.** Apparatus of mathematical statistics, linear programming methods, fuzzy set theory and expert assessment methods, scale theory, Bayesian approach to forecasting models, computer modeling.

**Findings.** The dynamics of consumption of electric energy for different periods of time is analyzed, the influence of the pandemic factor on the process of formation of demand for electric energy is established. A verbal-numerical scale has been developed for a comprehensive assessment of the impact on the demand for electric energy of such a complex social phenomenon as a pandemic. A model for forecasting the demand for electrical energy was formed using the Bayesian approach and an expert's assessment, which made it possible to use retrospective data on electrical energy consumption and take into account the uncertainty of the social factor influencing the pandemic.

**Originality.** The model for forecasting the demand for electrical energy has been further developed, which, unlike others, takes into account the factor of randomness of social processes and a verbal-numerical scale, which makes it possible to reduce the error in predicting the consumption of electrical energy.

**Practical value.** The research results are useful for enterprises specializing in the generation, transmission and distribution of electrical energy to consumers. The presented results make it possible to reduce the error in forecasting the demand for electric energy, taking into account the factor of randomness of social processes.

**Keywords:** *demand for electricity, forecasting, uncertainty, power system, Bayesian method, Covid-19, expert judgment*

**Introduction.** Liberalization of the energy market has brought the issue of forecasting the price and demand for electricity to the forefront. To form adequate forecasting models, it is necessary to consider new time challenges that affect the level of demand. The pandemic has been one of such factors since 2020.

In Ukraine a severe lockdown was introduced by the Cabinet of Ministers of Ukraine from March 12<sup>th</sup> to April 3<sup>rd</sup>, 2020. On March 25<sup>th</sup> the Cabinet of Ministers of Ukraine introduced a state of emergency throughout Ukraine until April 24<sup>th</sup> [1] which was then extended until May 1<sup>st</sup>. However, on May 4<sup>th</sup> the quarantine was extended until May 22<sup>nd</sup>, yet it was simultaneously eased. Due to the policy of restrictions, large consumers of electricity, such as businesses and commercial enterprises, were forced to close or switch to a minimum level of operation.

From 1991 to 1997 electricity consumption dropped significantly to 160 billion kWh, during the 2000s this figure changed considerably and in 2018, 2019 and 2020, respectively, amounted to 135.72, 120.22, 117.90 billion kWh per year. From the above data it can be concluded that the energy system of Ukraine is designed for a much higher level of con-

sumption than it has been observed in the recent years. Besides, with the amount of electricity consumption, which was observed in 1992, changes in a certain group of consumers do not significantly affect the total consumption at the national level. But with consumption at the level of recent years, a change in the workload schedule of a certain group of consumers is likely to have a significant effect on the overall consumption picture of the country.

It is also important to note that the share of electricity consumption by the household sector is gradually increasing. Since 1992 we have seen a downward trend in consumption in Ukraine while there is an upward trend in the share of consumption by the household sector. Therefore, the study on the impact of the pandemic outbreak on the energy sector of Ukraine, namely the household consumer, is a very important and urgent task, as well as consideration of different stages of the pandemic as a factor influencing the consumption by household consumers in solving the problem of consumption forecasting.

Until 2020 phenomena that cause changes in the habits and lifestyle of the population and are associated with viral diseases were not considered as an agent affecting the process of forecasting demand for electricity. To assist scientists, researchers, managers and politicians in better understanding

the effects of the pandemic on Ukraine's energy sector, this study attempts to identify the possible impact of the pandemic factor on electricity consumption by individual consumer groups. Therefore, this article determines the dependence of the level of electricity consumption on the level of pandemic development and the severity of the quarantine measures.

**Literature review.** The issue of studying the impact of the pandemic on the energy sector and other sectors of the economy is one of the fairly common, which is considered by scientists from different countries. In particular, the study [2] presents the impact of COVID-19 on the Ukrainian and Hungarian sectors of electricity and assesses its intensity and dynamics of the process. It is reported that after the coronavirus outbreak in Ukraine and Hungary, electricity consumption fell as businesses shut down and people switched to "stay home" mode. In both countries, energy needs began to decline almost immediately after government regulations on emergencies. This paper particularly draws parallels between electricity use, national quarantine restrictions and changes in economic, business, social and industrial activities. The problems of increasing the set capacity and generating potential of alternative energy sources are being discussed in connection with the reduction of demand for electricity during a pandemic.

The article [3] presents the impact of the COVID-19 pandemic on the Polish energy market. There is also an analysis of electricity consumption during the economic downturn. The data were compared with typical periods of last year, the paper also contains the analysis of changes in prices in the Polish electrical energy market.

The study [4] analyses the data on electricity consumption until the end of May 2020, examining both the demand for electricity and variables that may affect the voltage level in the grid. The article presents the results of research conducted within three US states: California, Florida and New York. The results show that the impact of the pandemic on electricity demand is not a simple reduction, but what is more, there are noticeable differences between the regions under consideration.

[5] studies the influence of quarantine restrictions on electric load and electricity production in the distribution system of the Italian city of Terni. It is stated that quarantine restrictions did not significantly affect the generation of renewable energy sources. There was also an increase in household consumption and a decrease in consumption due to reduction of commercial activity and reduction of production. [6] examines the impact of the pandemic on the operation of electricity grids in Israel, Estonia and Finland, investigates factors such as changes in electric power production and consumption, frequency stability and the relationship between low consumption and high share of renewable energy sources.

Given the presented analysis, the issue of taking into account the factors of randomness of social processes in forecasting the demand for electricity is crucial and insufficiently studied.

**Unsolved aspects of the problem.** The publications presented for analysis do not consider the problem of forecasting electricity consumption, which is important when introducing market relations.

Also, the results presented in papers [2–6] do not allow us to fully assess the impact of the randomness factor in the formation of demand for electricity by sectors.

**Purpose.** The aim is to identify opportunities to factor in the randomness of social processes when forecasting the demand for electricity to reduce error.

**Methods.** The tasks of the study were set in accordance with the aim and they are: 1) to conduct a comprehensive analysis of changes in electricity demand in terms of quarantine measures; 2) to develop a verbal-numerical scale that can be used when making an expert decision to reduce error; 3) to search for opportunities to include the cross-impact of economic sectors and consumers to be considered in forecasting algorithms; 4) to test methods to factor in the randomness of social processes. The solution of the stated tasks was per-

formed using the apparatus of mathematical statistics, linear programming methods, fuzzy sets theory and expert evaluation methods, scale theory, Bayesian approach to forecasting models, computer modelling as a means of research.

**Results.** According to the National Power Company "Ukrenergo" (hereinafter TSO), at the beginning of the quarantine restrictions the average electric power consumption per day in Ukraine decreased by 7.2 % compared to the same period in 2019 [4]. In April 2020 electric power consumption in Ukraine decreased slightly more than in March – by 7.5 % on average per day compared to April 2019. Starting from May 12<sup>th</sup>, 2020, after the ease of restrictions on movement, the downward trend in electric power consumption stopped.

Based on the analysis of five months of quarantine in 2020, the largest reduction in consumption is observed in the engineering industry – by 19 % [4]. Consumption in the chemical and metallurgical sectors increased slightly – by 16.8 and 10.8 %, respectively. In the transport sector, from January to May, electric power consumption decreased by 7.8 %. The largest increase in electric power consumption is observed in the household group of consumers – by 19.8 % [4]. According to the TSO, during the quarantine period the morning peak of electric power consumption shifted from 9 a.m. to 10–11 o'clock. The volume of electric power consumption before the pandemic on weekdays during the morning peak was about 18.5–19 GW, with the introduction of strict quarantine restrictions, this value decreased by 3.2 GW [4].

The evening peak of consumption in the pre-quarantine period was 19.2–19.6 GW. By the end of April 2020, the amount of electric power consumption was 17.8 GW, and in mid-May – up to 16.3–16.8 GW [4]. Fig. 1 shows the daily electric power consumption for the period with strict quarantine measures, as well as in comparison to similar periods in 2019 and 2018. The impact of the pandemic can also be seen on the monthly schedule of electric power consumption for 2020 compared to 2019 and 2018 (Fig. 2) whereas the maxi-

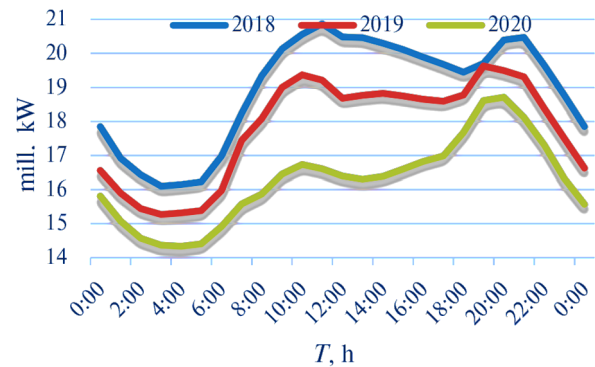


Fig. 1. Daily electric power consumption in Ukraine for March 26<sup>th</sup>, 2018, 2019 and 2020

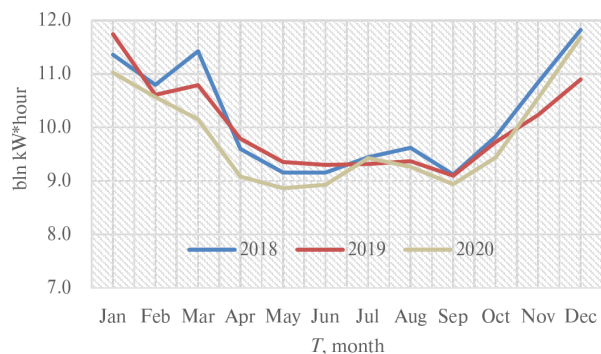


Fig. 2. Schedule of monthly electric power consumption for 2018, 2019 and 2020

imum deviation between the schedules of 2019 and 2020 was recorded in April – by 7.5 percent (in April 2019 – 9791.2 million kWh, in April 2020 – 9082.5 million kWh).

The trend towards reduction in electric power consumption during the pandemic also persists in most countries, both at the state and city levels, for example, independent system operators of New York and California reported 10 and 12 % reduction in electricity demand, respectively, after the curfew [7, 8]. Similarly, [9] introduced 10 % reduction in electricity demand in Europe, and there was also a change in the schedule of daily workload with a shift in the early morning and evening peaks of consumption. Compared to the average value from 2015 to 2019, the total average of electric power production in 16 European countries fell by 9 % (25 GW) in April 2020, where fossil energy production decreased by 28 % (24 GW), nuclear energy went down by 14 % (11 GW), while renewables increased by 15 % (15 GW) [10]. Although the fact that overall energy demand is declining is simple and clear, the implications are very complex for different energy types and consumption patterns in different regions.

This study is especially important for Ukraine due to the fact that it is currently impossible to control the consumption of the household sector, the amount of electric power consumption by a group of household consumers is calculated on a residual basis. The reason for this is the lack of modern accounting devices, so the information obtained in this study by forecasting demand with consideration for the randomness factor of social processes can be used in the distribution process when making a model of demand in the electrical energy market.

The peculiarity of the forecast in this study is the allowance for the factor of the pandemic, the impact of which is difficult to express mathematically in the form of any series. Given the mentioned feature in terms of solving the problem, it is recommended to use methods based on fuzzy logic or expert evaluation. The Bayesian methodology provides a reasonable way to combine prior knowledge with observable data to obtain new and improved estimates of, for example, demand. In addition, Bayes estimation has the ability to characterize its uncertainty by means of probability statements, which has become another major reason for its use in practice. Thinking in terms of probability is intuitive and can be an extremely useful tool in decision making. This feature of decision-making has made Bayesian analysis extremely popular in various fields – from medical diagnostics to machine learning [11].

The purpose of solving this problem is to minimize the error in the process of forecasting the demand for electricity. To do so it is necessary to consider the factors influencing the predicted parameter. Such factors include the type of day (working/non-working), the average temperature per month, social factors. This article considers the impact of a social factor, namely the pandemic, on the demand for electric power.

Therefore, time series of  $y_{\theta}(t)$  type are investigated in the calculations. In addition, the function of the time series can be formalized as follows:  $y_{\theta}(t) = f_{\theta}(t) + \xi_{\theta}(t)$ , where  $f_{\theta}(t)$  is a certain time function;  $\xi_{\theta}(t)$  represents independent random variables that affect the process of electric power consumption.

In this study, the process of forecasting the demand for electric power refers to the tasks of short- and medium-term forecasting of time series of the first and second levels. A necessary condition is that each time series of the first level  $y_i^1(t)$  is the sum of a certain number of time series of the second level  $y_i^2(t)$ .

Hence, we set the conditions that must be met by the time series under consideration:

- the need to simultaneously predict time series of the first and second levels;
- maintenance of general trends for significant periods of time;
- the forecast model must meet certain indicative conditions (expert evaluations).

**Bayesian method for solving the problem of forecasting demand using expert evaluations.** As we consider retrospective data on the electricity consumption of the country as a whole and of consumer groups separately, there is some uncertainty. Besides, in this study we consider the social factor influencing the time series of electricity consumption, namely the pandemic factor. This factor can be expressed both linguistically and in the form of a scale, which also introduces an element of uncertainty when included in the forecast model. Since the influence of social factors such as quarantine restrictions on the population is difficult to calculate, it was decided to use the method of forecasting with the involvement of experts.

Works [12, 13], for example, are devoted to the use of Bayesian approach and the advantages in solving the problem of forecasting demand include:

- the ability to include retrospective demand data and draft a preliminary distribution for further analysis. When new information about demand appears, the previous a posteriori distribution can be used as a priori;
- it is also recommended to use this method for small data samples and in cases where there is uncertainty.

The disadvantages include:

- bulkiness of computations;
- lack of a reasonable way to determine the prior. Bayesian methods require the skills to translate subjective a priori beliefs into mathematically formulated a priori ones.

**Development of a verbal-numerical scale to determine the level of influence of a social factor.** The impact of the pandemic on the demand for electric power is noticeable, yet it is very difficult to assess and express the nature of the impact mathematically. Expert evaluation involves a decision made by a person with some experience on the subject under study, while there is a factor of uncertainty. Therefore, to reduce the error in the decision-making process of the expert, it is necessary to develop a verbal-numerical scale of the impact of the pandemic factor on the level of electric power consumption.

As revealed from the analysis of the literature and statistical data, the severity of quarantine restrictions has an impact on the level of electric power consumption. Thus, we will make a scale of the pandemic factor influence on the zone colour and the severity of quarantine restrictions (Table 1).

This verbal-numerical scale is based on experimental estimates of the impact of the pandemic factor on the demand for electric power. Individual time intervals at which the restrictions were applied according to the zone colour were investigated. Afterwards, the actual level of decline in electric power consumption in percentage terms was determined.

Table 1

Verbal-numerical scale for estimating the impact of the pandemic factor

Zone colour				
Green	Yellow	Orange	Red	Total lockdown
Scale of verbal estimates of the severity of quarantine restrictions				
Mild quarantine	Moderate severity of quarantine measures	Moderate severity of quarantine measures	Strict quarantine measures	Very strict quarantine
Scale of numerical estimates of the severity of quarantine restrictions				
1	2	3	4	5
Possible change in the level of electric power consumption, %, of national electric power consumption				
0.5–1.4	1.5–2.5	2.6–3	3.1–6.4	6.5–8

It is recommended to use the developed verbal-numerical scale in the decision-making process by authorized persons (experts).

**Peculiarities of using the Bayesian method for the problem of forecasting the total consumption.** To solve the problem of forecasting the demand for electricity, the forecast of the factors that are part of the time series of demand is performed, the block diagram of the method is shown in Fig. 3. Let the properties of demand be expressed by a parameter  $\theta$ . The preliminary idea of the properties of demand is based on data  $I_a$ . Formalization of this information is carried out by adding an a priori distribution of the parameter  $\theta$ , which is conditional in relation to  $I_a$ . Retrospective data  $x$  are formalized using predictive function  $f(\theta, x)$

$$h(\theta/x, I_a) = \frac{h(\theta/I_a) \cdot f(\theta/x)}{\int h(\theta/I_a) f(\theta/x) d\theta},$$

where  $h(\theta, I_a)$  is an a priori distribution of the parameter  $\theta$ , conditional in relation to  $I_a$ ;  $f(\theta/x)$  is forecast function, conditional with respect to  $x$ ;  $h(\theta, x, I_a)$  is a posteriori shift of parameter  $\theta$ , conditional with respect to the source information  $I_a$ , and the observed data set.

Assume that the time series of demand can be described by a model

$$x_t = b + \xi_t,$$

where  $b$  is unknown average;  $\xi_t$  is a random variable that has a normal distribution with zero mean and known variance.

We write  $\xi_t$  in a simplified form

$$\xi_t = N(\theta, \sigma_\xi^2).$$

Thus, the demand over a period has a probability distribution

$$f(x_t, b) = N(b, \sigma_\xi^2).$$

If the value of the variance is accepted as known, then the problem lies in defining  $b$ . The evaluation of the decision maker can be described by the distribution  $b$

$$h_0(b) = N(\bar{b}', v_b'),$$

where  $v_b'$  is estimation variance  $\bar{b}'$ .

Consider the example of using the Bayesian method to predict the demand for electricity at the power system level, taking into account the uncertainty factor [14]. The input data are retrospective data on electric power consumption for 2020 (Fig. 4) and expert evaluation of the impact of the pandemic factor on the energy sector of the country as a whole. The expert's estimate depends on the severity of quarantine restrictions and the zone colour put in force on the territory.

The initial a priori information is retrospective data on monthly electricity consumption within 2020 (Fig. 1). In order to do the calculation, it is necessary to set initial values. Proceeding from the analysis of consumption data for 2020, as well as basing on the analysis of quarantine restrictions and the

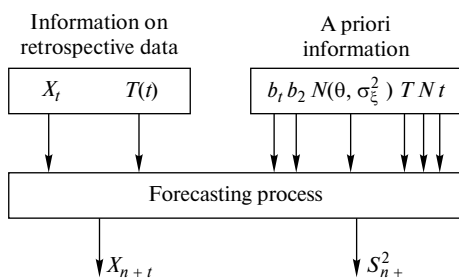


Fig. 3. Block diagram of the forecasting method using the Bayesian approach

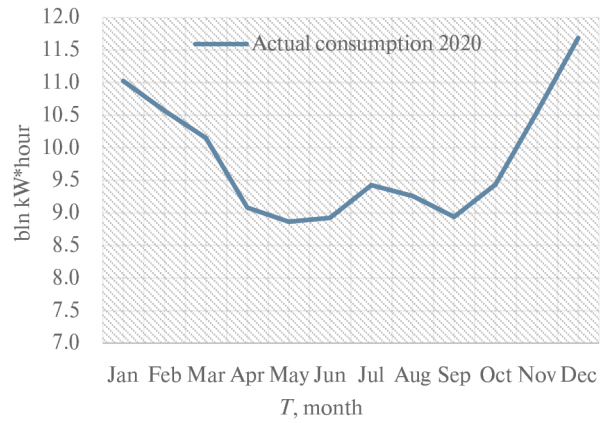


Fig. 4. Initial data for 2020 to forecast electric power consumption

zone colour the expert draws conclusions about the possible impact of social factors on the level of consumption and sets the following characteristics:

$W_{actual}^l$  is the lower limit of electricity consumption set by the expert;

$W_{actual}^u$  is the upper limit of electricity consumption set by the expert;

$\Delta W_{actual}^l$  is the difference between the lower limit of the expert's estimate and the actual value of demand;

$\Delta W_{actual}^u$  is the difference between the upper limit of the expert's estimate and the actual value of demand.

From the data set in the previous step, we calculate the coefficient of the equation  $b_1$  and  $b_2$

$$b_1 = \frac{W_{actual}^l + W_{actual}^u}{2};$$

$$b_2 = \frac{\Delta W_{actual}^l + \Delta W_{actual}^u}{2}.$$

We determine the elements of the covariance matrix  $V$

$$v'_{11} = \frac{(W_{actual}^l + W_{actual}^u)^2}{11};$$

$$v'_{22} = \frac{(\Delta W_{actual}^l + \Delta W_{actual}^u)^2}{11}.$$

We accept the value  $v'_{12} = 0$  and  $v'_{21} = 0$ .

According to the actual values of electric power consumption with  $T = 11$ , we determine the covariance-variation matrix of the a priori distribution. The matrix is as follows

$$Z' = \begin{bmatrix} x_1, \dots, x_{11} \\ T_1, \dots, T_{11} \end{bmatrix}.$$

The parameters of the forecasting model are calculated in the following way

$$G = Z' \cdot Z';$$

$$g = X \cdot Z';$$

where  $Z'$  is transposed matrix;  $Z'$  is inverse matrix;  $X$  is unit matrix;  $g$  is unit matrix of the demand forecasting model.

Let us determine the inverse matrix  $V^{-1}$

$$V^{-1} = G / \sigma_\xi^2,$$

where  $G$  is a parameter of the forecast model;  $\sigma_\xi^2$  is variance of the random variable of the component of the forecasting model.

When there is no information about variance  $\sigma_\xi^2$ , it is accepted as 2–3 % of the average range of demand according to the expression



$$\bar{x} = \frac{\sum_{t=1}^T x_t}{T}.$$

In the next step we determine the inverse matrix  $V^{-1}$  by the expression

$$V''^{-1} = \frac{\hat{V}^{-1}}{|V'|},$$

where  $V^{-1}$  is union matrix;  $|V'|$  is matrix determinant  $V'$ .

We find the inverse covariance-variation matrix of the adjusted distribution  $V''^{-1}$

$$V''^{-1} = V'^{-1} + V^{-1}.$$

The parameters of the electricity demand forecasting model are determined

$$B = V'' \left( V'^{-1} b_c + \frac{g}{\sigma_\varepsilon^2} \right),$$

where  $B$  is matrix determinant of the forecast value of demand for electric power;  $b_c$  is the average value of the deviation coefficients according to the results of the examination.

Therefore, the estimated value of electricity consumption in the power system of Ukraine will be

$$X_{T+\tau} = B(T + \tau).$$

For quality estimate of forecasting at each step we use the indicator.

MAPE is known as mean absolute percentage deviation

$$MAPE = \frac{100}{n} \cdot \sum_{i=1}^n \frac{|y_i - \hat{y}_i|}{y_i},$$

where  $y_i$  is the actual value of the electrical load/power output of the renewable sources of energy;  $\hat{y}_i$  is forecast value of electric load/output power of the renewable sources of energy;  $n$  is a sample volume.

From the results of the study (Table 2 and Fig. 5) it can be concluded that the error of the forecasting method is within acceptable limits. This study did not consider the full range of

Table 2

Forecast results

Month	Actual value, million kWh	Forecast value, million kWh	Calculation error, %
01.2021	11347.7	11089.3	2.3
02.2021	11134.6	10712.3	3.8
03.2021	11327.9	10626.9	6.2

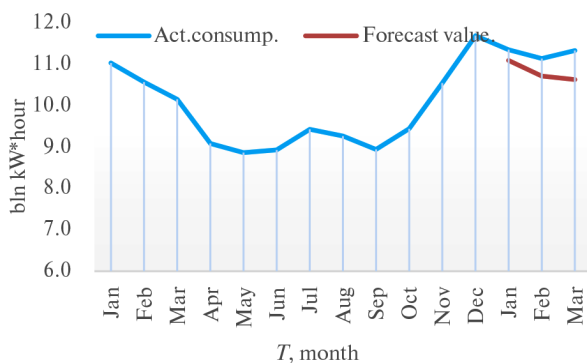


Fig. 5. Forecast results (blue – actual consumption; red – forecast results)

solutions to the problems of forecasting the demand for electric power, for further research the issue of improving the quality of expert estimate to improve the accuracy of forecasting could be included. To do so, it is possible to create within the algorithm itself a scale of factors or a list of factors that have an impact through the pandemic, which may potentially affect the level of demand for electric power under the spread of viral infection.

Furthermore, in further research it is practical to consider the solution of the task set at the regional level only, as well as work out the corresponding scale or the list of factors to increase of quality of an expert estimate.

**Conclusions.** According to the results of the analysis, it was found that the randomness formed by such social factors as the pandemic significantly affects the process of formation of demand for electricity; the biggest impact was observed in April 2020 – 7.5 %.

It is proposed to consider the randomness factor of social processes when forecasting the demand for electricity.

A Bayesian model for forecasting electricity demand using expert estimate was developed, which allowed us to use short time series of retrospective data on electricity consumption and take into account the uncertainty of the social factor of the pandemic when forming the demand for electricity. The smallest error was achieved in the first step of forecasting – 2.3 %.

The calculations were made using expert estimates based on the severity of quarantine restrictions and the zone colour in force in the country. The depth of expert estimate processing also affects the forecasting error.

A verbal-numerical scale has been developed for a comprehensive evaluation of the impact of such a complex social phenomenon as the pandemic on the demand for electric power. Besides, these results are used in expert decision-making in the process of solving the issue of forecasting the demand for electric power.

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## Урахування фактору випадковості соціальних процесів при прогнозуванні попиту на електричну енергію

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**Мета.** Урахування фактору випадковості соціальних процесів при прогнозуванні попиту на електричну енергію для зменшення похибки.

**Методика.** Апарат математичної статистики, методів лінійного програмування, теорії нечітких множин і методів експертного оцінювання, теорії шкал, Байєсовський підхід до моделей прогнозування, комп'ютерне моделювання.

**Результати.** Проаналізована динаміка споживання електричної енергії за різні періоди часу, встановлено вплив фактору пандемії на процес формування попиту на електричну енергію. Розроблена вербально-числова шкала для комплексного оцінювання впливу на попит на електричну енергію такого складного соціального явища, як пандемія. Сформована модель прогнозування попиту на електричну енергію з використанням Байєсовського підходу та оцінки експерта, що дозволила використати ретроспективні дані споживання електричної енергії та врахувати невизначеність соціального фактору впливу пандемії.

**Наукова новизна.** Набула подальшого розвитку модель прогнозування попиту на електричну енергію, яка, на відміну від інших, ураховує фактор випадковості соціальних процесів і вербально-числову шкалу, що дозволяє зменшити похибку прогнозування споживання електричної енергії.

**Практична значимість.** Результати дослідження корисні для підприємств, що спеціалізуються на генерації, передачі й розподілу електричної енергії споживачам. Представлені результати надають можливість зменшити похибку прогнозування попиту на електричну енергію при врахуванні фактору випадковості соціальних процесів.

**Ключові слова:** попит на електричну енергію, прогнозування, невизначеність, енергосистема, метод Байєсу, Covid-19, експертна оцінка

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