A Forecast Model of Energy Security Level in The System of Managing Energy Efficiency at Enterprises

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Abstract .he paper emphasizes the importance of managing an energy-efficient development of enterprises by designing a forecast model of energy security level in the system of enterprise management. The paper aims to forecast likely scenarios for enhancing energy security, identify major priorities and discover new ways to ensure energy efficiency at enterprises. The paper employs the following research methods: synthesis and analysis – to identify the essence and value of scenario modelling; theoretical generalization – to determine the main components of energy security at enterprises; classification – to study the impact of each component of energy security at enterprises on the choice of optimal scenario development; logical generalization – to justify the relevance, aim and objectives of the research; the method of rising from the abstract to the concrete – to develop and substantiate forecast trends in the changes of energy security level. Results: weight coefficients of energy security components based on scenarios have been formed; an algorithm for forecasting energy security level at enterprises based on scenarios has been built; forecast trends in the changes of energy security level have been determined; forecast trend models of energy security level at enterprises based on the proposed scenarios have been designed.

Keywords: Model, Forecast, Scenario, Energy Security, Energy Efficiency, Enterprise

1 Introduction

Today's conditions of economic management encourage enterprises to be more self-efficient and adapt to changes in external influences associated with rising energy costs and destabilization in energy supply to realize their economic interests and benefit from their competitive advantages. In this regard, the establishment of a system for managing energy security at enterprises is an important condition for functioning and improving the energy efficiency of socio-economic entities.

It is vital to develop an effective system of managing energy security at industrial enterprises since they take significant losses and are close to bankruptcy.

It can be explained by the following factors: continuous interaction between industrial enterprises and environmental factors as a major source of threats causing destabilizing effects; certain unproductivity of industrial enterprises and the possibility of taking measures for its timely elimination; energy security management is the only way of optimizing industrial production; requirements of a market economy for ensuring energy security as a factor in sustainable development of enterprises and promotion of their competitiveness [1].

The use of forecast models is one of the important elements of a structural model for the system of managing energy security at enterprises. Given this system seeks to ensure enterprises' safety management and, thus, ensure their energy-efficient development, one can indicate about strategic intentions of senior management to achieve these goals.

Therefore, it refers to complex and multi-faceted processes of managing and achieving strategic goals set by enterprises. Strategic planning is one of the most important aspects of strategic management, being a promising tool for the scenario method.

The scenario method aims to identify several goals, which are different in content but seek to realize the goals of strategic development [2]. Two, three or more scenarios are possible for strategic planning to increase energy security. Two scenarios allow one to generate two opposite ideas about the future (pessimistic and optimistic). Three scenarios indicate that one scenario serves as a forecast, being "optimal". More than three scenarios stimulate divergent thinking and can be used to form certain ideas [3].

The scenarios of achieving an optimal level of energy security at enterprises can be characterized as follows: 1) optimistic; 2) pessimistic; 3) realistic.

2 Related works

Such scholars as [4] at work models energy security scenarios for Ireland using long term macroeconomic forecasts to 2050, with oil production and price scenarios from the International Monetary Fund, within the Irish TIMES energy systems model. The analysis focuses on developing a least cost optimum energy system for Ireland under scenarios of constrained oil supply.

In [5], studies the first, there is a need to better understand how sources of insecurity can develop over time and how they are affected by the development of the energy system. Second, the current tendency to study the security of supply for each energy carrier separately needs to be complemented by comparisons of different energy carrier's supply chains.

As a result [6] three distinct perspectives on energy security have emerged: the “sovereignty” perspective with its roots in political science; the “robustness” perspective with its roots in natural science and engineering; and the ‘resilience’ perspective with its roots in economics and complex systems analysis.

At present, the energy security challenges are increasingly entangled so that they cannot be analyzed within the boundaries of any single perspective. To respond to these challenges, the energy security studies should not only achieve mastery of the disciplinary knowledge underlying all three perspectives but also weave the theories, methods and knowledge from these different mindsets together in a unified interdisciplinary effort.

In the paper [7] compares three different indices, “Energy Sustainability Index”, “International Index of Energy Security Risk” and “Energy Architecture Performance Index” along with their variants to examine if they provide consistent results for various countries. A comparative assessment reveals that the three indices provide different country rankings, which are inconsistent.

This situation is akin to three blind men groping the elephant with each one measuring a different part of the body and asserting that only their assessment is true. Further analysis reveals that countries which rank in the top of the list of different indices are insensitive to differences in construction of the index and it can be inferred that they have robust energy systems, which partly resolves the conflict [8-12].

3 The model of energy security level

The paper presents the authors’ scenarios under which they reflect changes in the priority components of energy security to simulate the level of energy security at enterprises under study. These components include resources and energy (P1), equipment and technologies (P2), environment and society (P3), finances and economy (P4), organization and management (P5).

Using the scenario method, one can determine the impact of each component of energy security at enterprises and achieve an optimal level of energy security under certain conditions [13-18].

Table 1 shows weight coefficients of components of energy security at enterprises for each of the five possible scenarios based on expert assessment.

Table 1. Weight coefficients of energy security components based on scenarios

Components of the integrated indicator	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Resources and energy (P_1)	0.352	0.242	0.187	0.121	0.099
Equipment and technologies (P_2)	0.242	0.352	0.121	0.187	0.242
Environment and society (P_3)	0.187	0.121	0.352	0.099	0.187
Finances and economy (P_4)	0.121	0.099	0.242	0.352	0.121
Organization and management (P_5)	0.099	0.187	0.099	0.242	0.352

Such components as resources and energy (P1) and equipment and technologies (P2) become the most important ones under scenario 1 (0.352 and 0.242). Under scenario 2, such a component as equipment and technologies (P2) is more significant than resources and energy (P1). At the same time, organization and management (P5) can be valued more than environment and society (P3) (0.187 and 0.121). Under scenario 3, more importance is given to environment and society (P3) and finances and economy (P4), whereas less importance – to organization and management (P5) (0.099). As evidenced by scenario 4, such components of energy security as finances and economy (P4) and organization and management (P5) are characterized by top positions among all the components. Scenario 5 focuses on organization and management (P5).

Consequently, these scenarios allow one to analyze changes in energy security level at enterprises under study, taking into account the changes in weight coefficients of each component.

The paper employs an economic and mathematical dynamic model, reflecting the development of the modelled system through trends, to forecast the level of the integrated indicator in future periods and obtain the necessary information. It is required to assess and forecast the impact of internal and external threats on the energy security of enterprises.

Forecasting based on a time series of certain economic indicators belongs to one-dimensional forecasting methods, at the core of which is extrapolation, that is, a continuation of trends observed in previous periods towards future periods. Such as approach assumes that a forecasted indicator is shaped by many factors one cannot identify or investigate. Under these conditions, the dynamics of changes in this indicator is associated not with factors but the passage of time, manifested in the creation of one-dimensional time series.

The paper employs statistical methods of forecasting based on the use of historical information presented through time series, that is, dynamics series structured by temporal attributes. The main idea behind time series analysis lies in building a trend based on past data and further extrapolation of this line into the future. However, in doing so, complex mathematical procedures are used to obtain the exact value of the trend line and trace any fluctuations [19-25].

Thus, the time series implies the sequence of levels of the series:

$$\{y_i\} = y_{1,}\, y_{2,\dots}\, y_n \tag{1}$$

where i – natural numbers that correspond to the moments or intervals for measuring the value under study.

y_i – levels of the series.

Measurements are made at regular intervals.

Such a method of forecasting can be presented through the following mathematical model:

$$y_{t+1} = f\left(t, y_t, \dots y_{t-m,}\, x_t^{(1)}, x_{t-m_1,}^{(1)}\, x_t^{(2)}, \dots, x_{t-m_2,}^{(2)} x_t^{(k)}, \dots, x_{t-m_k}^{(k)}\right) \tag{2}$$

where y_t – the value of the indicator being forecasted at a certain moment of time t;

$x_t^{(i)}$ – the value of i factor at a certain moment of time t, which affects y;

m, m_1, m_k – memory length of the series used during forecasting.

The differences between different methods are related to the structure of the input x and the type of function $f(\dots)$. Therefore, the paper uses one of the types of dependencies used in modern forecasting methods, namely polynomial dependence. Time series models in which the dynamics of the mean value of the series are described by analytical dependence on time only are called trend models [26-30]. The trend model implies the analytic function of the form below:

$$y = f(t, \vec{a}) \quad (3)$$

where t – the time set in certain units (years);

$\vec{a}$ – a vector of parameters under which the model most accurately describes the dependence of the series $\{y_i\}$ on time t and ensures minimum fluctuations in actual and modelled levels:

$$F(\vec{a}) = \|y_t - f(t, \overrightarrow{a)}\| \quad (4)$$

at a certain time interval $t: t_{first} < t < t_{last}$.

It must be acknowledged that the function $f(t, \vec{a})$ can be not only a traditional analytical (polynom) but also harmonic complex neural network.

The input data for forecasting the level of energy security at enterprises are calculated actual values of the level of this indicator under the proposed scenarios of ten machine-building enterprises. Here is an algorithm that can forecast the level of energy security at enterprises under study (Fig. 1).

It is necessary to graphically represent the levels of the dynamic series, which is taken as the basis for making forecasts, to establish the form of the mathematical equation according to which they should be made.

Visual analysis of the diagram can show what most accurately reflects a smooth trend of the series, namely straight or curved lines. At the same time, the analysis of coefficient values of correlation and approximation of different models proves that it is essential to choose a polynomial trend model.

4 Experiments

The paper applies an algorithm for forecasting energy security level at enterprises and reveals probable dependencies by using a forecast trend model for enterprises under study. Table 2 shows forecast trends under five scenarios.

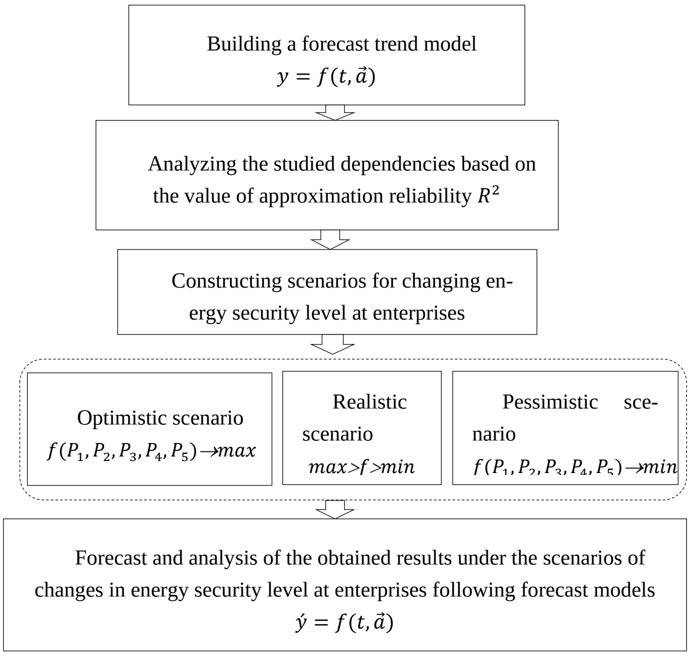

Fig. 1. An algorithm for forecasting energy security level enterprises under study based on scenarios

Table 2. Forecast trends in changes in energy security level at enterprises under study

Years	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	Actual	Expected	Actual	Expected	Actual	Expected	Actu-al	Expected	Actu-al	Expected
2013	0.155	–	0.163	–	0.156	–	0.158	–	0.165	–
2014	0.149	–	0.159	–	0.15	–	0.152	–	0.159	–
2015	0.158	–	0.16	–	0.159	–	0.159	–	0.166	–
2016	0.152	–	0.162	–	0.149	–	0.154	–	0.161	–
2017	0.196	–	0.165	–	0.182	–	0.188	–	0.202	–
2018	–	0.187	–	0.163		0.174	–	0.180		0.193
2019	–	0.211	–	0.168		0.190	–	0.199		0.215
2020	–	0.244	–	0.172		0.209	–	0.225		0.248

Thus, table 2 shows that the expected values of energy security level under these scenarios are characterized by an increasing trend. Besides, some positive dynamics proves a success in enterprises' activities, as well as senior management's ability to deal with problematic situations, eliminate obstacles and threats to the external and internal environment under unstable conditions. However, one should take into account the maximum expected values of energy security level at enterprises under a certain scenario to achieve maximum results in future periods. The paper also attempts to demonstrate trend models under each scenario of enterprises under study and calculate the values of approximation reliability R^2 to determine optimal, real and pessimistic scenarios. Figure 2 shows the forecast trend model of energy security level at enterprises under study under scenario 1.

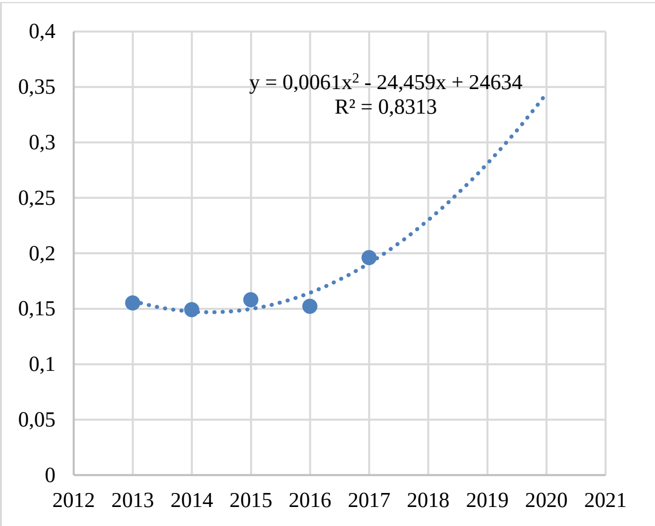

Fig. 2. The forecast trend model of energy security level at enterprises under study under scenario 1

Figure 2 shows that the predicted values of energy security level at enterprises under study can increase under scenario 1. The obtained coefficient of R^2 now amounts to 0.8313. It means that the level of energy security depends on the resources and energy component by 83%, other components – by 17%. Indeed, R^2 shows how much of the variation in performance indicators is related to the variation in factor indicators, given that the closer the value of the coefficient to 1, the stronger the dependence. When evaluating regression models, it is interpreted based on its accordance with the data model. Regarding adoptable models, R^2 should be no less than 50%. Models with R^2 above 80% can be considered quite good. If R^2 is equal to one, the variable is accurately described by the considered model.

Figure 3 shows the expected trends at enterprises under study under scenario 2.

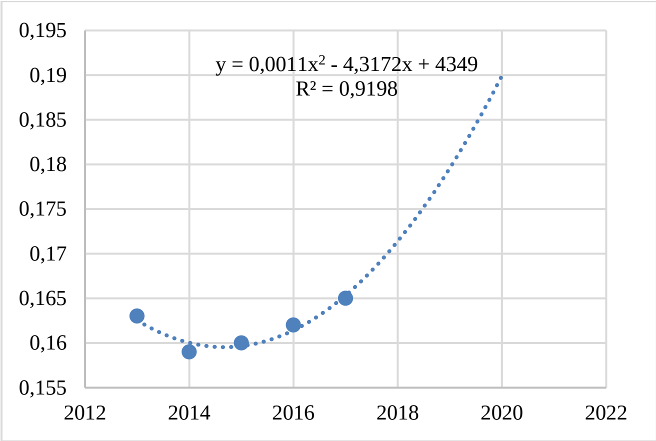

Fig. 3. The forecast trend model of energy security level at enterprises under study under scenario 2

Analyzing the obtained results, one can see that scenario 2 allows the trend model of energy security level at enterprises under study to acquire the maximum value of R^2 under these conditions.

If R^2 is equal to 0.9198, it implies certain close links and indicates that 91.98% of the variation in energy security level at enterprises under study may be caused by the variation in such a component as equipment and technologies. The coefficient of remaining determination (1-0.9198) demonstrates that 8.02% of the variation in energy security level is attributable to other causes.

Figure 4 shows the forecast trend model of energy security level at enterprises under study under scenario 3. It proves that the forecast increasing trends for the indicator under scenario 3 are slightly slower than under the previous scenarios.

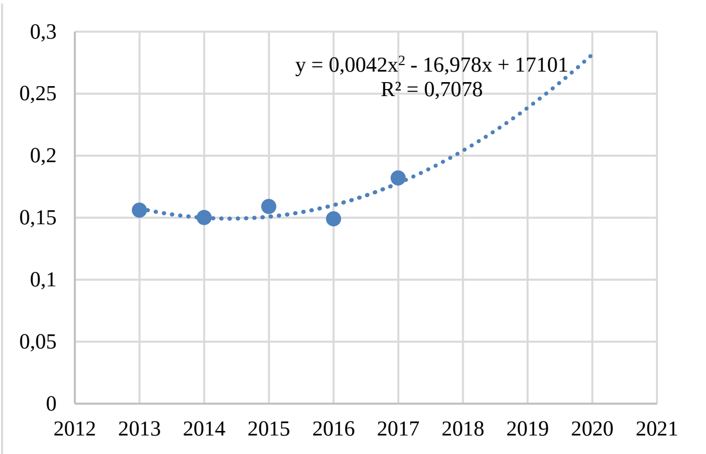

Fig. 4. The forecast trend model of energy security level at enterprises under study under scenario 3

Thus, the level of energy security at enterprises under study is much less dependent on the impact of such a component as environment and society compared to other ones (resources and energy, equipment and technologies). If R^2 is equal to 0.7078, it interprets the impact of other factors at the level of 29.2%.

Under these conditions, the forecast trend model of energy security level at enterprises under study under scenario 3 has lower indicators of the energy security level of at enterprises under study in future periods compared to the forecasts under scenarios 1 and 2.

Figure 5 shows the forecast trend model of energy security level at enterprises under study under scenario 4.

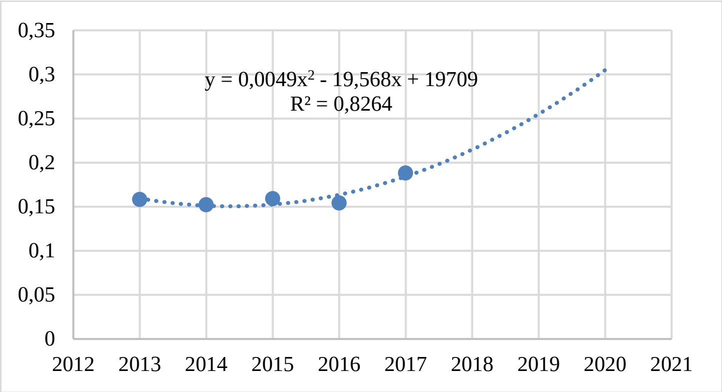

Fig. 5. The forecast trend model of energy security level at enterprises under study under scenario 4

Thus, one can conclude that the forecast is optimal since the obtained coefficient of R^2 is now equal to 0.8264. It proves that the level of energy security depends on the economic component by 82.64%, other components – by 17.36%. One should also pay particular attention to some similarities between the conditions of scenarios 1 and 4 since R^2 becomes 0.8313 if the priority is given to resources and energy and 0.8264 – in case of the priority of the economic component. It confirms the complexity and close links between certain components when achieving the maximum level of energy security at enterprises under study.

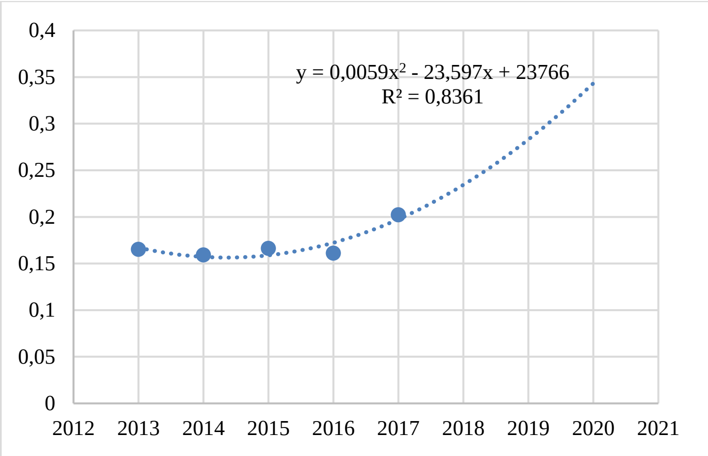

Fig. 6. The forecast trend model of energy security level at enterprises under study under scenario 5

Figure 6 demonstrates the results of the expected level of energy security at enterprises under study under scenario 5 employing the forecast trend model.

Scenario 5 assumes the priority of such a component as organization and management. In this case, the coefficient of determination is a quantitative characteristic, which leads to the conclusion that the constructed econometric model agrees with the empirical information based on which it is constructed.

Thus, the accuracy of the econometric model is equal to 83.61%. If R^2 is equal to 0.8361, it interprets the impact of other factors at the level of 16.39%. Such an impact on energy security level is one of the greatest among the proposed scenarios and their forecast models, which somewhat enhances the value of organization and management as the main component for a certain enterprise.

Table 3. The scenarios for forecasting energy security level at enterprises under study based on trend models

Scenarios	Polynomial trend model	The value of approximation reliability	Expected values		
			Years		
			2018	2019	2020
Optimistic (P_5)	$y=0.0059x^2-23.597x+23766$	$R^2=0.8361$	0.193	0.215	0.248
Realistic (P_1)	$y=0.0061x^2-24.459x+24634$	$R^2 = 0.8313$	0.187	0.211	0.244
Pessimistic (P_2)	$y=0.0011x^2-4.3172x+4349$	$R^2 = 0.9198$	0.163	0.168	0.172

Table 3 shows the results obtained from the constructed forecast trend models and presents optimistic, realistic and pessimistic scenarios for enterprises under study Analyzing these calculations, it is possible to confirm the existence of the revealed optimistic, realistic and pessimistic scenarios and expected values of energy security level according to each of them.

According to the proposed algorithm for forecasting the level of energy security at enterprises by scenarios, three scenarios for the possible development of the indicator under study have been developed. The obtained results allow one to conclude that this algorithm reflects rather high-quality forecast trends. Regarding the studied enterprises, the obtained forecast values for optimistic, realistic and pessimistic scenarios for achieving the level of energy security are reliable.

Therefore, the proposed methodical approach to determining the level of energy security based on forecast trend modelling makes it possible to identify the impact of individual components of energy security on its overall level and, thus, create scenarios for achieving the expected value following the optimality of each scenario under these conditions. The proposed methodical approach can be useful for enterprises since it contributes to thorough integrated assessment of the overall level of their energy security, its forecasting for future periods, which, in turn, will positively affect energy supply and energy efficiency of production and economic activities.

5 Conclusion

Thus, an optimistic scenario is underpinned by the priority of organization and management since the indicators of energy security level at enterprises can be maximized for the next three years in case of its realization. Under scenario 5, enterprises can reach the energy security level of 0.248 in 2020. A realistic scenario depends on the presence of priority (P_1) and can help to reach the energy security level of 0.211 in 2019 and 0.244 in 2020. A pessimistic scenario (P_2) is characterized by the lowest level of energy security. If such a scenario is chosen as the main one in maximizing the value of energy security level, enterprises will not be able to increase this indicator to the maximum achievable level.

All the constructed models can help to reach rather high values of determination coefficients, which indicates the high quality of these models. This situation is linked to the lack of drastic changes in energy security level. Therefore, this forecasting method is quite successful for the enterprise, and the results of this approach are accurate.

Therefore, the paper proves that energy security level at enterprises under study should be modelled employing the scenario method, which can analyze the priority components of the integrated indicator of energy security. It also presents the author's economic and mathematical dynamic model in which the development of the modelled system can be represented as a trend to forecast the level of the integrated indicator of energy security in future periods. Besides, it applies the method of statistical forecasting based on the use of historical information presented in time series.

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