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APPLICATION OF EXTREME VALUE PROBABILITY ASYMPTOTIC THEORY IN CHINA'S ENERGY RISK PREDICTION

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Abstract

Extreme value theory is a theory that deals with situations that are extremely far from the median of a probability distribution. It is often used to analyze situations with rare probabilities, such as earthquakes and floods that occur once in a hundred years. It is often used in risk management and reliability research. This article demonstrates some simple applications of extreme value asymptotic probability theory in predicting China's energy risks. First, the article introduces the main classical results of extreme value asymptotic probability theory, and demonstrates the method of using graphical methods to construct quantile graphs to calculate energy data, and gives examples of quantile graphs.

The article calculates and analyzes the risks faced by China's major energy consumption and imports and exports in the past decade, and predicts the development trends of some energy economic indicators in China from 2023 to 2026 through quantile graphs constructed by extreme value asymptotic probability theory. The results show that the results predicted by the quantile diagram constructed by extreme value asymptotic probability theory are basically accurate, so extreme value asymptotic probability theory should be more widely used in the field of energy economic forecasting. At the same time, this article puts forward some suggestions in order to contribute to China's low-carbon sustainable development.

Keywords: energy risk, risk prediction, extreme value asymptotic probability theory, energy statistics.

ПРИМЕНЕНИЕ АСИМПТОТИЧЕСКОЙ ТЕОРИИ ВЕРОЯТНОСТИ ЭКСТРЕМАЛЬНЫХ ЗНАЧЕНИЙ В ПРОГНОЗИРОВАНИИ ЭНЕРГЕТИЧЕСКИХ РИСКОВ КИТАЯ

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Реферат

Теория экстремальных значений – это теория, которая рассматривает ситуации, чрезвычайно далекие от медианы распределения вероятностей. Она часто используется для анализа ситуаций с редкой вероятностью, таких как землетрясения и наводнения, которые случаются раз в сто лет, а также в управлении рисками и исследованиях надежности. В статье продемонстрированы некоторые простые возможные приложения асимптотической теории вероятностей экстремальных значений для прогнозирования энергетических рисков в Китае. Приводятся основные классические результаты асимптотической теории экстремальных значений, демонстрируется метод расчета энергетических данных с использованием графических способов построения квантиль-диаграмм, приведены примеры построения графиков квантилей.

В работе рассчитываются и анализируются риски, с которыми столкнулись основные отрасли потребления, импорта и экспорта энергии в Китае в последнее десятилетие, и при помощи квантиль-диаграмм прогнозируются тенденции развития некоторых энергетических и экономических показателей Китая с 2023 по 2026. Высокая точность результатов, полученных при помощи квантиль-диаграмм, построенных по асимптотической теории экстремальных значений, позволяет сделать вывод о необходимости более широкого использования данной теории в области прогнозирования экономики энергетики. Предложены направления устойчивого развития Китая, направленные на снижение уровня выбросов углекислого газа.

Ключевые слова: энергетический риск, прогнозирование риска, асимптотическая теория экстремальных значений, энергетическая статистика.

Introduction

Risk prediction refers to a measure to predict the abnormalities that may occur in the work process and work results before work, and formulate countermeasures to prevent accidents.

The current global economic uncertainty is increasing and the downside risks are relatively large, which may have an unexpected impact on China's economy, which has a weak foundation for recovery [1]. China should accelerate the use of policy tools and actively respond to changes in the external environment. Therefore, making good predictions on the risks of the low-carbon economy will help the government to better formulate economic policies, strengthen international policy coordination, and improve the effectiveness of policies.

The World Bank's latest Global Economic Prospects report released in 2024 predicts that global economic growth will slow for the third consecutive year, from 2.6 % in 2023 to 2.4 % in 2024, nearly three-quarters of a percentage point lower than the average level in the 2010s [2]. The report pointed out that this will make 2020–2024 the slowest five-year growth in the global economy in 30 years.

According to the World Bank's estimates, in 2023, the growth rate in East Asia and the Pacific will rebound from 3.4 % in 2022 to 5.1 % [2], mainly due to a brief surge in economic activity after China lifted its epidemic blockade measures at the beginning of the year.

However, the analysis pointed out that the effect of China's economic restart faded quickly: investment growth was dragged down by the continued weakness of the real estate industry, and the decline in sales and prices increased the financial pressure on real estate developers; the export sector faced the challenge of weak external demand. Although consumption improved at the end of the year, consumer confidence was still far below the pre-epidemic level.

The World Bank believes that the instability caused by the higher procyclicality and volatility of fiscal policies will drag down the growth prospects of commodity exporters in developing economies for a long time. To this end, the report recommends that these countries take a series of policy measures to alleviate this drag, including by establishing a fiscal framework that helps to restrain government spending, adopting a flexible exchange rate system, and avoiding restrictions on international capital flows [2].

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Usually, in the prediction of economic policy concepts, economists or researchers will use time series method, indicator analysis method and factor analysis method to predict economic trends or investment trends [3].

Time series method is a prediction method that studies the changing form of time series by analyzing its components, continuing the past development trend and extrapolating the future. Its main methods include moving average method, weighted moving average method, exponential smoothing method, least square method, etc.

Indicator analysis method is a prediction method that determines the signs of changes in the economic situation by analyzing the interrelated indicators or indicator groups that reflect economic changes, studying the "trend" indicators that predict economic turning points and the "warning" indicators that predict serious problems in the economy.

Factor analysis method is a method of prediction by establishing an economic mathematical model with the causal relationship or structural relationship between the prediction object and the factors that affect it.

In the current commonly used economic forecasting methods, economic forecasts cannot always be accurate because human will and activities are involved in the economic process. Its accuracy has a gradual improvement process. Here we propose a new forecasting method: combining extreme value theory, using extreme value probability asymptotic theory to find special application methods to determine and predict the risks of extreme economic emergencies. In recent years, extreme value probability theory has made significant progress in theory, but it has not been promoted in practical applications. The extreme value distribution model is a very effective tool for studying extreme value phenomena and extreme value random variables. Therefore, more and more people are aware of the great potential of extreme value theory in the application of extreme events. It is particularly pointed out that extreme value theory is a theory that simulates the tail of data distribution, so it can be applied to the prediction of extreme value data.

Research History

Extreme value theory is an important branch of order statistics, which mainly studies the extreme value distribution and its characteristics, especially the terminal characteristics of the distribution. Its research methods and scope have undergone great changes.

In the early stage, extreme values only studied what kind of distribution the maximum and minimum values in a series of independent and identically distributed random variables should obey. Fisher-tippett LHC (1928) published the first theoretical article on extreme value limits, and gave the Fisher-tippett theorem, which shows that the distribution of the maximum or minimum value of the sample converges to one of the three distributions when the sample size tends to infinity. His research method greatly simplified the study of the value limit properties, and divided a variety of distribution functions into three relatively simple categories according to the tail properties, thus establishing the foundation of this theory [4].

B. V. Gnedenko (1943) gave the first rigorous mathematical proof of the Fisher-tippett theorem. In 1950, British statisticians mainly carried out research on generalized extreme value distribution, which showed three types of extreme value distribution in one form, making parameter estimation simple, because it was no longer necessary to select one model from three models, thus avoiding the cumbersome procedures [5]. Gumbei (1960) applied extreme value theory to specific statistical problems and proposed a statistical method now called block method, which is to divide the data into many intervals according to a predetermined length, and then select a maximum or minimum value from each interval for modeling. However, selecting only extreme values from a large amount of data will lose the information contained in other large amounts of data [5].

Pickands (1971) proposed a new extreme value research method, that is, a method of selecting data above a certain limit for analysis, called POT method. The limiting form of its distribution function tends to generalized Pareto distribution (GPD). His work deepened the understanding of the concept of extreme value and its inherent meaning, that is, not only the maximum and minimum values are called extreme values, but also data above a certain limit should be extreme values, so they all need to be studied [6].

Research status

Since energy plays a very important role in economic growth and social development, China has always attached great importance to energy security and risk prediction. With the changes in the internal and external environment of China's economic development and the initial elimination of the risks of the COVID-19 pandemic, quantitative research on energy security assessment has increased in recent years.

Most traditional energy risk prediction methods adopt an indicator evaluation model. According to the number of indicators required for evaluation, it can be divided into single indicator evaluation and multi-indicator evaluation [7]. Single indicator evaluation can directly show the core part of the research problem, but it may not be accurate or objective when facing complex systems. Multi-indicator evaluation can fully reflect the characteristics of the research object, but it is too complicated and may also lead to different results due to different subjects and weight distribution.

At the same time, most of the research on energy risk prediction focuses on the operation of power equipment or the evaluation of energy system operation [1]. In view of the huge and complex energy data, China currently does not have a better prediction method.

From a statistical point of view, extreme values refer to the maximum and minimum values of a random process in a certain period, usually located at the tail of the data distribution. Extreme value distribution refers to the probability distribution of the maximum or minimum values in the observed values. Based on the tail characteristics of the distribution, possible extreme value movements can be further predicted. In other words, extreme value theory is a model technology used to predict the risks of abnormal phenomena or low-probability events. It has the ability to estimate beyond sample data and can accurately describe the quantiles of the tail of the distribution.

Regarding the application of extreme value theory in prediction, the current research of domestic and foreign scholars focuses on the use of extreme value asymptotic distribution probability theory to predict natural disasters. Wang Bojun et al. used four calculation methods to predict climate extremes and precipitation probabilities [8]; Zhang Youming et al. calculated the recurrence cycle of corresponding earthquakes and the number and probability of corresponding earthquakes that may occur in a certain period of time in the future based on the modified extreme value theory statistics [9]; Bykob also used extreme value asymptotic distribution theory to calculate forest fire cycles and predict risks [10]. Deng Wenping et al. chose to use extreme value theory based on actual forest stand data and adopted the generalized Pareto model to obtain the maximum number of trees in the forest stand at each given diameter class [11]. Song Xiaomeng et al. analyzed the probability statistical characteristics of extreme precipitation in Beijing based on extreme value theory and explored the applicability of different extreme value distributions in the study of extreme precipitation in Beijing [12].

This paper will use extreme value asymptotic probability theory to predict a series of Chinese energy indicators and try to prove its rationality.

Extreme value asymptotic probability theory

The Fisher-Tippett theorem (1928) is the core of extreme value theory, which mainly explains the convergence properties of extreme value distributions [13].

There exist two real number sequences {α_n } and {β_n } (where $\alpha_n > 0$), such that

$$\lim_{n\to\infty} P\left(\frac{X_{(n)}-\beta_n}{\alpha_n} \le x\right) = H(X)(x \in R),$$

where H(x) is a non-degenerate distribution function, then H(x) is one of the following three types of extreme value distribution functions:

ξ > 0, its distribution function is

$$\Phi_{\xi}(x) = \begin{cases} 0, & x \le 0 \\ \exp\left(-x^{-\xi}\right), & x > 0 \end{cases}, \tag{1}$$

ξ = 0, its distribution function is:

$$\Lambda(x) = \exp\left[-\exp(-x)\right], \quad x \in R, \tag{2}$$

$\xi < 0$, its distribution function is

$$\Psi_{\xi}(x) = \begin{cases} \exp\left[-(-x)^{\xi}\right], & x < 0 \\ 1, & x \geq 0 \end{cases}. \tag{3}$$

This theorem describes that no matter what form the original distribution function F(x) takes, the sample maximum after linear transformation converges to a random variable with one of the above three distribution functions according to probability. Therefore, this theorem occupies a core position in the extreme value theory system and provides a solid foundation for further research [14].

Among them, (1) is collectively called Gumbel distribution, (2) is collectively called Frechet distribution, and (3) is collectively called Weibull distribution [15]. These three distributions are collectively called extreme value distribution. The extreme value type theorem states that if M_n undergoes a linear transformation, the corresponding normalized variable $M_n^* = (M_n - b_n) / a_n$ converges to a non-degenerate distribution according to the distribution. Then, no matter what form the underlying distribution F(x) takes, this limiting distribution must belong to one of the three types of extreme value distribution. Therefore, the extreme value type theorem provides an extreme value convergence theorem similar to the central limit theorem.

One practical difficulty of the one-dimensional extreme value distribution model is that we cannot directly determine which of the three distribution types the extreme value data obtained belongs to. In order to facilitate statistical inference, the generalized extreme value distribution (GEV) proposed by Uon Mrses (1954) and Jenkinson (1955) is an approximate distribution of extreme values [16–18].

The generalized extreme value distribution function is:

$$H_{\xi,\ \mu,\ \sigma}(\mathrm{x}) = \begin{cases} \exp\left[-\left(1+\xi\frac{x-\mu}{\sigma}\right)^{-\frac{1}{\xi}}\right], \xi \neq 0, 1+\xi\dfrac{x-\mu}{\sigma} > 0 \\ \exp\left[-\exp\left(-\dfrac{x-\mu}{\sigma}\right)\right], \xi = 0, -\infty < x < +\infty \end{cases}. \tag{4}$$

Among them, $-\infty < \mu < \infty$ is the location parameter, $\sigma > 0$ is the scale parameter, and $-\infty < \xi < \infty$ is the shape parameter. The tail behavior of the distribution function F(x) of the data X_i determines the shape parameter ξ of the generalized extreme value distribution H(x). If the tail of F(x) decays exponentially, then H(x) is of Gumble type and $\xi = 0$. The Gumble family includes thin-tailed distributions such as normal distribution, lognormal distribution, exponential distribution and Gamma distribution; if the tail of F(x) decays with a power function, then H(x) is of Frechet type and $\xi > 0$, and the Frechet family includes heavy-tailed distributions such as Pareto distribution, Cauchy distribution, and Student-t distribution; if the tail of F(x) is finite, then H(x) is of Weibull type and $\xi < 0$, and the Weibull family includes uniform distribution, β-distribution, etc.

In sampling distribution theory, the normal population is a population that is often used in practice and is widely used. Compared with the normal population, when the population is non-normal or the distribution of the population is unknown, it is very difficult to require the precise distribution of the sampling distribution, or the derivation is too complicated and difficult to apply.

However, when the population is an arbitrary distribution or the distribution is unknown, the asymptotic distribution of some statistics can be obtained using the large sample method. These methods have a generalizable significance. As long as a suitable function can be constructed, more sampling distributions can be obtained for further statistical inference.

Here is an example of the application of extreme value distribution theory in exploring the prediction of wind speed in Chongqing, China: Researchers used short-term wind speed data from Shapingba District, Chongqing from 1990 to 1999 to conduct extreme value distribution analysis of the annual maximum wind speed [3]. Firstly, the extreme value type I (Gumbel), extreme value type II (Frechet) and extreme value type III (Weibull) distributions were used to fit the extreme value distribution of the annual maximum wind speed. Then, the maximum wind speeds of each month from 1990 to 1994 were selected as samples, and the sample size was expanded to 60 to fit the asymptotic distribution of the monthly extreme value of the maximum wind speed. The parameters of the three extreme value distribution functions were estimated according to the principle of least squares method, moment method and variable substitution method. The fitting effect of the distribution function of the annual maximum wind speed under short-term wind speed data and the asymptotic distribution function of the monthly extreme value was compared through the parameter estimation goodness index. A better extreme value distribution function was selected from the 4 groups of 12 distribution functions as the extreme value distribution function of the annual maximum wind speed. Finally, the optimal asymptotic distribution of the extreme value of the annual maximum wind speed in Chongqing under short-term wind speed data was obtained by comparing and analyzing the parameter estimation index and wind speed estimation results with GPD.

Finally, the extreme value type III (Weibull) distribution gave the best fitting goodness of fit and extreme wind speed estimation value. For areas lacking long-term wind speed observation data, researchers used limited short-term data to analyze the monthly maximum wind speed to fit the asymptotic distribution of wind speed extremes in the area, which was significantly better than using annual maximum wind speed records. In a sense, the increase in sample size reduces sampling errors.

The extreme values of energy-related economic factors are unstable in the mathematical sense as random variables, but their changes over time are stable in probability. Therefore, the distribution of extreme values of energy-related economic factors can be simulated by distribution functions, thus providing a theoretical basis and data reference for the prediction of the probability of extreme events.

In this context, we have compiled and integrated some indicators, built a database based on China's energy data from 2013 to 2021 or 2022, tried to use extreme value theory to predict the extreme value distribution of China's energy factors, and look forward to making some suggestions for the construction of low-carbon energy policies.

We constructed six indicators and attempted to predict China's future energy development by applying extreme value asymptotic probability theory to these indicators (Table 1).

Combining extreme value theory and extreme value asymptotic distribution theory, we use the following algorithm to process the data:

1. First, we list a part of China's processed energy data from 2013 to 2021 ($X_1, X_2, \ldots X_9$) (Table 2).
2. Second, we sort the values in ascending order ($X_1^* < X_2^* < \ldots < X_n^*$) to get a new data string (Table 3).
3. Based on the statistics of the variant sequences, we will build a graph and add a trend line that most accurately characterizes the variant sequences (Figure 1).
4. We use the obtained function to calculate the value of x_{10} to use it in predicting the series.

$$x_{10} = 16.308. \tag{5}$$

5. Calculate initial data and build a quantile plot based on that data (Table 4 and Figure 2).

Based on the relationship between the two sets of data, a quantile graph is constructed using a coordinate system:

$$\left(-\ln(-\ln(\frac{i}{n+1}), \ln(x_i)\right). \tag{6}$$

Table 1 – China Energy Indicators [19, 20]

Indicators	**Indicator values by year (2023–2025 – forecast)**												
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
1. Share of RES, %	10.535	11.293	12.086	13.834	14.425	14.845	15.395	15.799	16.182	16.308	16.343	16.253	16.036
2. Share of local unRES*, %	4.613	4.561	4.517	4.745	4.755	4.606	4.460	4.390	4.293	4.245	4.171	4.094	4.014
3. Energy independence (Ratio of energy imports to total energy consumption)	0.293	0.294	0.284	0.327	0.355	0.379	0.401	0.412	0.391	0.430	0.444	0.458	0.470
4. Energy transformation efficiency, %	73.0	73.1	73.4	73.5	73.0	72.8	73.3	73.7	73.2	73.2	73.8	73.9	74.0
5. Ratio of urban and rural per capita energy consumption	1.067	0.981	0.915	0.893	0.885	0.901	0.855	0.820	0.851	0.807	0.831	0.840	0.854
6. Coal's share of total energy consumption, %	71.3	70.0	68.1	66.8	65.3	63.9	62.8	62.2	61.8	61.3	61.0	60.9	60.9

*Local unRES means biomass energy, such as wood, crops, and municipal solid waste.

Table 2 – Share of renewable resources in China (2013–2021)

	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Ratio	10.535	11.293	12.086	13.834	14.425	14.845	15.395	15.799	16.182

Table 3 – New data string in ascending order

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Ratio	10.535	11.293	12.086	13.834	14.425	14.845	15.395	15.799	16.182

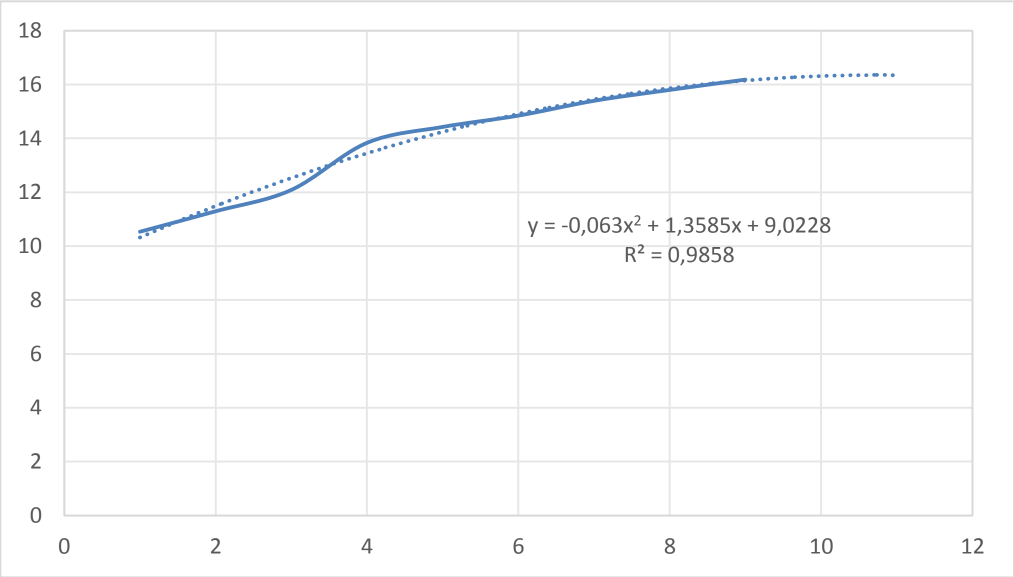

Figure 1 – Input data for predicting X_{10}

Table 4 – Initial data

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
$-\ln(-\ln(i/(n+1)))$	–0.83	–0.48	–0.19	0.09	0.37	0.67	1.03	1.50	2.25
lnx	2.35	2.42	2.49	2.63	2.67	2.70	2.73	2.76	2.78

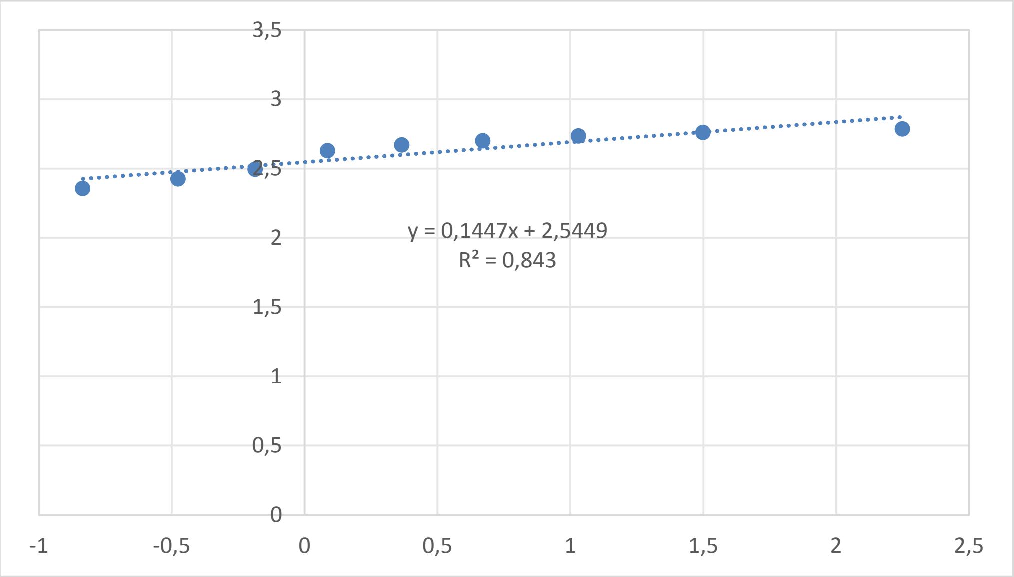

Figure 2 – Quantile chart of "share of renewable energy sources in China"

Table 5 – Maximum, minimum and average values of China's energy indicators from 2023 to 2026

Indicators		**2023**	**2024**	**2025**	**2026**
Indicator 1 Minimum	Maximum	19.735	19.742	19.638	19.458
	Minimum	11.122	11.377	11.630	11.861
	average	15.428	15.560	15.634	15.660
Indicator 2	Maximum	4.798	4.799	4.800	4.803
	Minimum	4.109	4.035	3.958	3.878
	average	4.454	4.417	4.379	4.340
Indicator 3	Maximum	0.506	0.523	0.540	0.555
	Minimum	0.280	0.283	0.286	0.290
	average	0.393	0.403	0.413	0.422
Indicator 4	Maximum	73.876	74.016	74.141	74.266
	Minimum	72.802	72.792	72.796	72.801
	average	73.339	73.404	73.468	73.533
Indicator 5	Maximum	1.011	0.995	0.980	0.965
	Minimum	0.740	0.746	0.755	0.768
	average	0.875	0.871	0.868	0.867
Indicator 6	Maximum	70.748	70.287	69.810	69.333
	Minimum	57.565	57.283	57.149	57.129
	average	64.157	63.785	63.480	63.231

1. Constructing the equation, we get:

$$Lnx = 0.1447y + 2.5449. \qquad (7)$$

2. By using the coefficient b and the constant a of the above equation, calculate the values of α and β and continue to build the indicator:

$$\alpha = \exp(-a);\ \beta = 1/b,$$

$$\alpha \approx 0.078;\ \beta \approx 6.911. \qquad (8)$$

Then for the distribution law of the indicator "share of renewable energy sources in China", we get the following equation:

$$F(x) = \exp[(-0.078x)^{-6.911}]. \qquad (9)$$

3. Calculate the maximum and minimum values of the indicator:

$$x_{min} = \exp[b\ (-\ln(-\ln 0,05)) + a] = 10.871;$$

$$x_{max} = \exp[b\ (-\ln(-\ln 0,95)) + a] = 19.583. \qquad (10)$$

By repeating similar calculations for other data, we obtain the maximum, minimum and average values predicted for these data in the next three years.

Conclusions

Through calculation, we can conclude that extreme value asymptotic probability theory has a strong correlation with predicting China's energy-related indicators, and can be used as a means of predicting China's energy risks.

The calculation results tell us that in 2024–2026, the change range of the corresponding energy indicators is not large, which means that China's energy development level will remain within a stable range in the short term.

However, although the Chinese economy has shown a certain degree of resilience and good development momentum in the past decade, the economic growth momentum is insufficient. The current global economy is still facing various uncertainties and large downside risks, so China needs to focus on the following aspects:

After the epidemic, developing economies will be hit harder than the economies of developed countries, as sluggish global trade and tightening financial conditions have seriously dragged down economic growth.

The current "multiple crises" in geopolitics, public health, environment and economy have begun to affect the world's energy trade policy. Some countries are increasingly banning the trade of strategic energy commodities and services on the grounds of "security risks". In addition, global trade is being realigned along geopolitical lines, especially in the wake of the Ukrainian crisis.

Suggestions and advises

Due to the increase in global economic uncertainty and the large downside risks, China's post-epidemic energy economy may have an unexpected impact. Therefore, China should accelerate the use of policy tools and actively respond to changes in the external market. Specifically, the following measures can be considered.

First, strengthen international coordination of energy policies and improve policy effectiveness. Under the current circumstances, China should enhance its ability to deal with energy import and export risks, specifically by strengthening energy policy coordination and improving energy transaction efficiency and coverage under the multilateral framework. Through international coordination of energy policies, trade barriers can be reduced, cross-border investment can be promoted, and inflation can be reduced from the source.

Second, increase the exchange rate flexibility of the RMB in energy trade. The Chinese government should play the role of the exchange rate as an automatic balancer for the balance of payments and attract foreign capital inflows to ensure energy security. This requires the Chinese government to promote the alignment of domestic market rules and systems with international standards, thereby improving credit ratings and ensuring the level of domestic energy resource management.

Finally, the government should introduce policies to ensure energy security. China should strengthen the energy safety net and deal with energy risks in a market-oriented and legal manner. This requires the government to strengthen the review and management of cross-border capital flows and maintain the stability of domestic and foreign energy markets through positive actions and communication.

References

1. Guoqing, L. Risk Prediction of Node Outage in High Proportion New Energy Grid / L. Guoqing, L. Dagui, X. Guilian // Power System and Clean Energy. – 2022. – Vol. 38, No. 6. – P. 106–115.
2. Annual Report 2024. – World bank group. – URL: https://www.worldbank.org/en/about/annual-report (date of access: 10.11.2024).
3. Qingzhen, M. Asymptotic distribution of annual extreme values of maximum surface temperature and maximum wind speed in Chongqing / M. Qingzhen, W. Zengwu, F. Xin // Journal of Chengdu University of Information Technology. – 2004. – No. 3. – P. 436–441.
4. Barakat, M. H. Asymptotic Distributions of the Generalized Range, Midrange, Extremal Quotient, and Extremal Product, with a Comparison Study / M. H. Barakat, M. E. Nigm, M. A. Elsawah // Communications in Statistics – Theory and Methods. – 2015. – Vol. 44, No. 5. – P. 900–913.
5. Shuli, W. Tail characteristics of α-skewed normal distribution and limiting distribution of extreme values / W. Shuli, P. Zuoxiang // Journal of Southwest Normal University (Natural Science Edition). – 2020. – Vol. 45, No. 9. – P. 19–22.
6. Pu, J. Asymptotic expansion of the extreme value distribution of the three-parameter type I generalized logistic distribution / J. Pu, L. Xinling, L. Tingting // Journal of Southwest University (Natural Science Edition). – 2020. – Vol. 42, No. 6. – P. 60–64.
7. Dan, S. China's primary energy security: influencing factors, evaluation and prospects. / S. Dan, X. Qinyuan // Economic Perspectives. – 2021. – No. 1. – P. 31–45.
8. Baijun, W. Application of asymptotic extreme value theory in climate extreme precipitation prediction / W. Baijun, C. Gangyi // Journal of Chengdu Meteorological College. – 1994. – No. 2. – P. 30–34.
9. Shanhua, C. Research and application of extreme value theory in earthquake prediction in coastal areas of Fujian Province / C. Shanhua, Z. Youming, Y. Yuxing // North China Earthquake Science. – 2013. – Vol. 31, No. 2. – P. 29–34.
10. Bykov, A. A. Prilozheniya asimptoticheskoj teorii veroyatnostej ekstremal'nyh znachenij k prognozirovaniyu riska ekstremal'nyh chrezvychajnyh situacij / A. A. Bykov // Strategiya grazhdanskoj zashchity: problemy i issledovaniya. – 2012. – No. 1. – URL: https://cyberleninka.ru/article/n/prilozheniya-asimptoticheskoy-teorii-veroyatnostey-ekstremalnyh-znacheniy-k-prognozirovaniyu-riska-ekstremalnyh-chrezvychaynyh (date of access: 10.11.2024).
11. Wenping, D. Estimation of self-thinning line of larch plantation based on extreme value theory / D. Wengping, L. Fengri // Journal of Nanjing Forestry University (Natural Science Edition). – 2014. – Vol. 38, No. 5. – P. 11–14.
12. Xiaomeng, S. Study on probability distribution of extreme precipitation in Beijing based on extreme value theory / S. Xiaomeng, Z. Jianyun, K. Fanzhe // Science China: Technological Sciences. – 2018. – Vol. 48, No. 6. – P. 639–650.
13. Fisher, R. A. Limiting forms of the frequency distribution of the largest and smallest member of a sample / R. A. Fisher, L. H. C. Tippett // Mathematical Proceedings of the Cambridge Philosophical Society. – 1928. – Vol. 24, No. 2. – P. 180–190.
14. Fréchet, M. Sur la loi de probabilité de l'écart maximum / M. Fréchet // Annales de la Société Polonaise de Mathématique. – 1927. – Vol. 6, No. 1. – P. 93–116.
15. Shusen, D. Asymptotic Normality of GLUE of Weibull Distribution or Extreme Value Distribution and Its Application / D. Shusen // Journal of Fujian Normal University (Natural Science Edition). – 1982. – No. 1. – P. 69–80.
16. Zishen, C. Comparative analysis of parameter estimation methods of generalized extreme value distribution / C. Zishen, L. Zengmei, L. Jianfei // Acta Scientiarum Naturalium Universitatis Sunyatseni. – 2010. – Vol. 49, No. 6. – P. 105–109.
17. Jenkinson, A. F. The frequency distribution of the an-nual maximum (or minimum) values of meteorological elements / A. F. Jenkinson // Quarterly Journal of the Royal Meteorological Society. – 1955. – Vol. 81. – P. 158–171.
18. Hosking, J. R. M. L-moments: Analysis and estimation of distributions using linear combinations of order statistics / J. R. M. Hosking // The Journal of the Royal Statistical Society, Series B. – 1990. – Vol. 52. – P. 105–124.
19. Energy Statistics Data Browser. – URL: https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser (date of access: 10.11.2024).
20. China Energy Statistics Yearbook. – P. 3, 7, 9, 58–59.

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