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# A NEURAL NETWORK MEASUREMENT OF THE LEVEL AND PACE OF GLOBAL ECONOMIC AND TECHNOLOGICAL DEVELOPMENT

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**Abstract.** The article considers the problem of measuring the level and rate of technical and economic development of countries in terms of technological change. Advantages of cognitive neural network approach to monitoring and quality analysis for integrating into a single model of economic, scientific-technological, innovative and other quantitative and qualitative components of growth, not amenable to traditional statistical analysis, with calculation of the forecast evaluation time of the reference trajectory of technical and economic development. Presents the results of the calculations. To improve the accuracy of the model trajectories are encouraged to use self-organizing Kohonen maps.

## 1 Introduction

A correct assessment of the level of technical development of the national economy, its position in the global energy required for the development of rational scientific-technical policy. Due to the unique features of each national economy has its own rational trajectory of future energy resources. Planning, possible only in the form of rough scenarios should be based on global trends of technical and economic development (TED) with the above national peculiarities. The most important of them is the situation in cross-country hierarchy TED. For this assessment is relevant model reference trajectory calculations, which sets the common for all countries of the reference system and scale, and serves as the basis for measuring the technical development of national economies.

Many researchers note that the global technological change generated by countries that are leaders in the life cycle of the relevant technological structures [1]. Although technological developments that make up the content of the life cycle of each technological structures occur in the world market, the economic structure of the countries most closely reflects the structure of the relevant specifications, and the dynamics of their TED - evolution of these specifications. Therefore, as the reference trajectory calculations can be considered the actual trajectory calculations leaders in their respective specifications.

Virtue of the laws of reproduction of social capital life cycle of a technological structure in a market economy is reflected in the specific form of Long Waves of economic conditions. The so-called Long wave, or Kondratieff waves, are the subject of study of

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special areas of economic research - analysis of long-term processes of social reproduction [2]. In modern periods allocate 5 Kondratieff long waves (Figure 1).

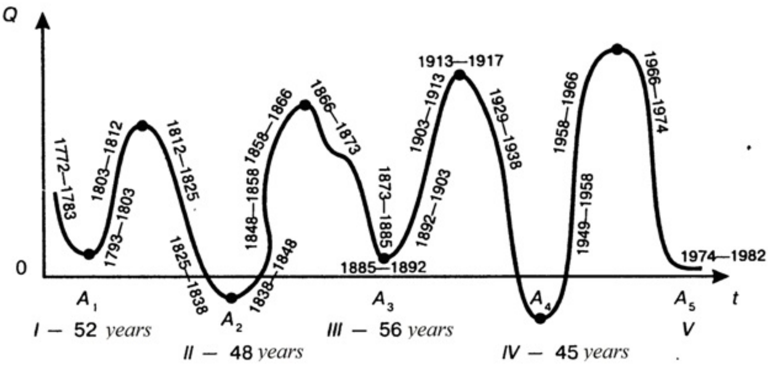


**Figure 1.** Modern periodization Kondratieff long waves.

In empirical studies of the Long waves was established in principle unidirectionality of what is happening in different countries, technological changes, the similarity of national trajectories calculations, as well as the tendency to synchronization of macroeconomic fluctuations and technological changes. In particular, the same form of the trajectories of energy resources in countries with market-based and policy-driven economy was identified in the structure of energy consumption in metallurgy and mining industry, in the dynamics of the transport infrastructure and other sectors of the economy [1]. The unidirectionality of energy resources in different countries, as well as the formation of a unified rhythm of the global economic system, due to the formation of the global market and rapid expansion of international economic relations since the industrial revolution. Experience macroeconomic research says about the possibility and fruitfulness of using cross-country comparisons for obtaining high-quality and fairly accurate quantitative conclusions, including the forecast of nature [1].

Research related to the modeling of global socio-economic processes in connection with technological development and resource limitations, were launched in the 1970s, the works of J.M. Forrester [3] and D. Meadows [4]. They had a great impact on researchers, and public opinion began to develop ecology, the spread of the idea of sustainable (sustainable - self-sustaining development. Although the research was a huge success, they at the same time were criticized by mathematicians, futurists, economists and sociologists. According to experts, the macro model of the world dynamics, created by the authors, was too mechanistic: it is not documented regional structure of the object, ignored political and social factors, there were differences with theories of economic growth, were not taken into account the adaptive capacity of the global system through social and scientific-technical progress. Following the publication of Forrester and meadows group was followed by the work of American, German, British, Japanese, Polish, Bulgarian and other researchers who tried to take into account the existing criticism. Next generation models were Multiregional description global development and description of the world market.

In Russia, studies were continued at the Computing center (under the direction of academician N.N. Moiseeev) and the Institute of system analysis (under the guidance of academician V.A. Gelovani). In global modeling can be distinguished publication [5] the staff of the Institute of system analysis of Russian Academy of Sciences S. Dubovsky and V. Britkov that have worked closely with D. Meadows and Club of Rome in 70-ies of the last century, made under the direction of academician V.A. Gelovani. In a macroscopic model of the system dynamics Forrester and Meadows were introduced control actions that will significantly expand and explore the range of possible scenarios of world development.

Significant results of scenario studies received in 2009-2010 as a result of execution of the subprogram "Mathematical modeling and systems analysis of the global dynamics" of the program of fundamental research of the Presidium of the Russian Academy of Sciences "Economics and sociology of knowledge" (scientific leaders, academicians, G.V. Osipov and V.A. Sadovnichy, a leading organization - Institute of applied mathematics to them M.V. Keldysh of RAS). The purpose of these studies is the analysis of the emerging trends of world development on the basis of mathematical modeling, the study of scenarios of development of the world system to 2030-2050 years, and arising in this context, alternatives.

In a broader theoretical framework for the issues in the institutionalization of socio-economic and environmental processes are closely linked to the adequacy of the models. Methods of research using global models, they can be divided into two groups - simulation and optimization models. The simulation model describes a closed system of equations, i.e., all functional relationships, the values of parameters and exogenous variables (including control actions) set in advance to the functioning of the model. The study simulated the system using a simulation model is to determine the impact of different assumptions about the functional relationships and the numerical values of the parameters and control actions on the system behavior. The system of equations optimization models is not closed - the part of the exogenous variables (control actions) is not set. The study of an object using an optimization model is to find the values of these variables, ensuring the achievement of pre a particular purpose, as a rule, optimizing a given functionality.

From well-known global models to simulation models include Forrester, Meadows and model of the Mesarovich-Pestel. The first three models represent a system of nonlinear differential equations. With this description in the model included pre-selected constant control mechanism, which is essentially a decision-making model, identified on the historical development of the system. In this case, the research system is to search the various "policies" and the analysis of their impact on system behavior. Under "policies" refers to various combinations of hypotheses about functional relationships, the structure of the steering mechanism, the numerical values of the parameters. This approach helps in the first stage to better understand the dynamics of the investigated processes, to identify possible critical trends. However, the fixation of the steering mechanism does not involve conscious of the changes humans have made to the existing trends of development and does not allow to analyze all the possibilities of the system when a valid control effects.

Thus, the construction of global models and research through various scenarios of world development has formed the research direction called "Global modeling". It can be defined as a set of mathematical, social and economic and other methods on the basis of information technologies applied to the study of global processes. The basic perspective and the novelty of the development of mathematical methods for global modeling, according to the authors, consists in the use and development of cognitive neural network technologies, which are defined as interdisciplinary intellectual solve semi-structured problems, with the aim of developing predictive solutions in the social and economic sphere. They are designed to improve those processes that involve people.

Experts differ in opinion, in which technological environment is now Russia is in the 4th or in the 5th? What potential growth opportunities to use? Where to look for the reserves? How to "jump" in the 6-th technological structure? The best way to overcome the crisis and prolonged depression caused by the change of Kondratieff cycles, as shown by the prominent German economist, Mens [6] is an innovative breakthrough, through the timely development and dissemination of basic technologies for the next 6th Kondratieff cycle. The period from 2010 to 2020 is thus the most favorable time to introduce a new wave of underlying technologies. In our opinion, a significant leap in understanding to build global models lies in finding an adequate way of measuring the level and pace of economic and technological development of countries and define meaningful indicators of the technical-economic growth. Note that in the scientific literature there is no common notion of "energy" or "the pace TED", with virtually no publications, of which we could understand how to measure these growth parameters.

## 2 Purpose and method

The purpose of this research is to develop the technique of multi-criteria neural network measuring the level and pace of global economic and technological development on complex of quantitative and qualitative indicators. To build a predictive model for the neural network is no requirement of stationarity of the process. Neural networks as universal tool that can accurately detect nonlinear patterns and relationships between the components of the multidimensional random processes.

## 3 Results and discussion

Anticipating the results of the comparative analysis of energy resources, it is necessary to highlight two factors. On the one hand, objects and territories of the States, regardless of the size and role in the overall economic development, are not self-contained entities and, despite the internal trends and relationships cannot plan its development from its own internal dynamics and proportions. On the other hand, although the countries, united international division of labour, develop according to the general directions of the feasibility of evolution, they vary significantly in terms of absolute level of performance and energy consumption (measured in relative units - per capita or per unit of national income), even if you are on the same level of energy. This is due to the historical, scientific, educational, cultural, psychological, climatic and other characteristics of each country, which are reflected in its economic structure. Therefore, to construct an adequate model for the trajectory calculations in the group of investigated parameters we introduce the qualitative component of growth is the productivity index of primary resources, which is measured as the ratio of GDP to the cost consumed by the economy is the primary raw material resources [7].

Primary resources – the totality of primary organic and inorganic resources, which in droves are used both for consumption and for further processing in the process of material production (food, construction materials, fuel and energy resources). Most developed countries with the lowest energy - consumption by main types of resources, nevertheless consume per capita 1.5-2.5 times more primary raw material resources than the state of the “second echelon” - Russia, Brazil, India and China. Productivity as an indicator of resource efficiency reflects the progress of science and technology. Even in the recession period (1991–1998) in Russia was quite intensive processes to improve the quality of products and services (Figure 2).

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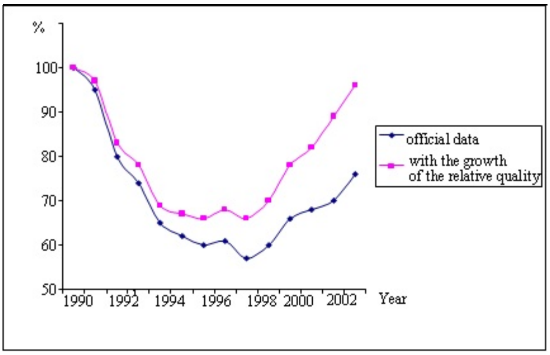


**Figure 2.** Russia GDP dynamics in 1990–2003, to the 1990 level.

This is reflected in the fact that the productivity of primary resources were increased on average by 2.3% per year. Considering the fact that during this period significantly decreased the dynamics of the qualitative components of growth for the United States (to 0.95% per year, compared with 2.3% per year on average over the previous 30 years), the index improved proportions exchange for the Russian economy amounted to $ 1,016. Since 1998, in the period of recovery of recovery, the dynamics of the qualitative components of growth for Russia grew to nearly 4% per year. However, because in this period also increased the qualitative component of growth for the United States (2.4% per year), the index of the changing proportions of the currency changed slightly to 1,017.

Therefore, the gap in economic development of Russia and the United States could be overcome provided that the rapid growth of productivity (science and technology) in Russia. When modeling the trajectory calculations will take into account that innovation reveal and define the essence of the technological process at the present stage of history. Selected quantitative and qualitative indicators of the feasibility of the development will complement the indicators of innovation potential of the country, divided into 4 groups:

1) indicators characterizing the financial component of the innovation potential (the share of investment relative to GDP, the share of investment in total and so on);

2) indicators characterizing the material component of the innovation sphere (the number of organizations involved in scientific activities, the cost of their fixed assets, the share of scientific organizations);

3) indicators of staffing component of innovative capacity (number of employees involved in innovation, their average wage, average age, their share toy);

4) indicators characterizing the resulting component of innovation capacity as a factor of economic growth and showing his ability to bring the effect (sales, costs and profit associated with innovative activity, the number of created, exported and imported technologies, patents filed and granted patents, their share).

Thus, as the trajectory calculations simulated multivariate time series that represents the combination of several one-dimensional time series, each of which describes the change over time of any of the listed features that characterize the object of the study (Figure 3).

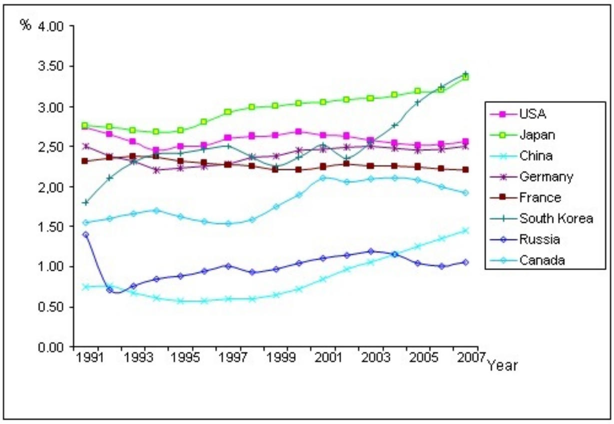


**Figure 3.** One-dimensional time series (indicator - the share of R & d expenditures in GDP) across countries.

For each year $t_i$ a separate country is represented by a point in a multidimensional (Figure 4 – three-dimensional) space of quantitative and qualitative characteristics.

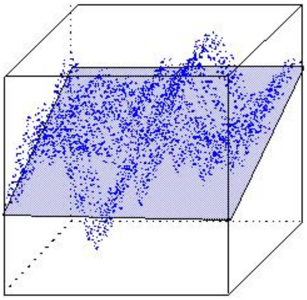

**Figure 4.** The three-dimensional space of input features.

Linear statistical processing of the data is not able to describe the curve calculations with reasonable accuracy. Used to solve problems of prediction of the statistical apparatus of the correlation analysis, which builds upon the previous values of one-dimensional random process, it is not possible to establish a causal connection settings predictable system as a whole. In addition, the building for each country its generalized curve TED (by linear compression space of input vectors) and their cross-national comparative the analysis is not entirely incorrect due, first, the "fluid" nonequilibrium nature of techno-economic development, with waves fall and rise (Kondratieff waves); and secondly, it is very important input parameters for constructing trajectories, in our opinion, should not be hardcoded - they depend on the national system of accounts in each country, and from historical, cultural, psychological, climatic and other characteristics of the country at the time of observation t, while the importance of the same parameters to build the model will be different for different technological structures.

Thus, the probabilistic approach cannot be considered as reliable and adequate tool for solving semi-structured problems. Limitations and disadvantages of the application of "classical" formal methods in solving semi-structured problems are the result formulated by the founder of the theory of fuzzy sets L. Zadeh, "the principle of incompatibility": "...the closer we come to the solution of real world problems, the more obvious that by increasing the complexity of the system, our ability to make accurate and confident conclusions about its behavior diminishes until a certain threshold beyond which precision and confidence become almost mutually exclusive concepts."

To improve the quality of the modeling, the authors propose to conduct a comprehensive neural network analysis of quantitative and qualitative indicators, which are in the process of learning are ranked weighting factors according to the level of significance for solving the problem. According to the available data samples are built and trained a time series Kohonen neural networks [8] , showing the dynamics of global economic and technological development, which is then used to calculate estimates of the level of energy, performance and energy consumption of individual countries and for forecasting future values of a multidimensional process. Their mapping on the reference and national trajectories TED allows to obtain a reliable assessment of not only speed, but also the level of technical and economic development of each country.

The main difference between self-organizing Kohonen maps from other models is clarity and ease of use (Figure 5).

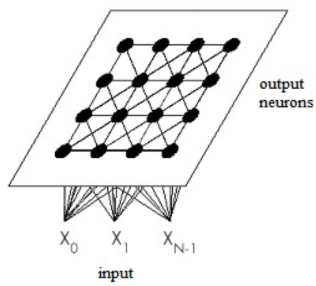


**Figure 5.** A neural network model of Kohonen.

These networks allow to simplify the multi-dimensional structure, they can be considered one of the methods of projection of the multidimensional space into a space with lower dimensionality. Figure 6 depicts a neural network model of the global techno-economic portrait, reflecting the hierarchy of countries in 2005 (for clarity, here we applied two-dimensional spline interpolation).

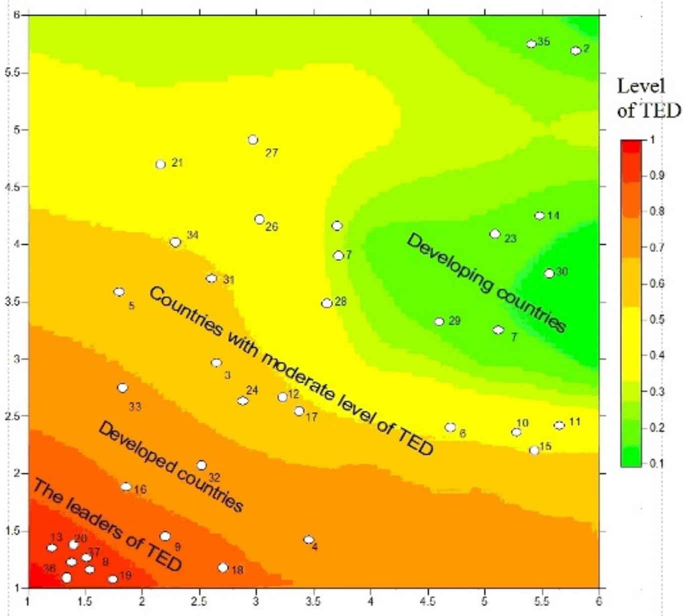


**Figure 6.** Neural network model of the global technical and economic portrait (2005).

Each country in terms of their energy in the current year is displayed specific cell on the map. Cells with identical coordinates contain countries with similar state energy. The farther to the map coordinates of the countries, the more different from each other, their feasibility portrait. In this case, the trajectory of the energy we can produce dynamic range of Kohonen neural networks (Figure 7), reflecting the global techno-economic portrait in the *i*-th year, each country is characterized by a set of parameters ($Y_i$, $A_i$, $B_i$, $C_i$), where:

$Y_i$ € [0;1] is the level of energy and fuel resources of the country in the *i*-th year;

$A_i$ is the actual distance (the number of years elapsed from the moment when the reference level parameter TED corresponded to the level of the country under consideration in the *i*-th year of observation);

$B_i$ – promising distance (the number of years it will take for this country, starting from the *i*-th year, to achieve the reference level of technical development in the *i*-th year of observation);

$C_i$ – conditional distance (the number of years required for the output to the reference trajectory).

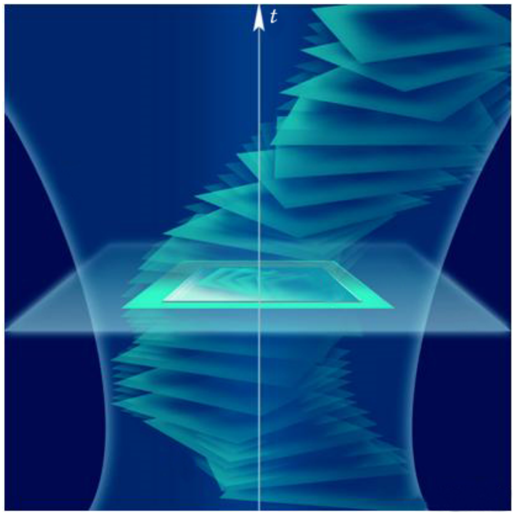


**Figure 7.** The model trajectory calculations as a time series of trained Kohonen neural networks in the multidimensional feature space.

## 4 Insights

Neural network clustering data (2005–2010) shows that the analyzed countries are divided into 4 main categories in terms of their energy (Table.1), which takes values from 1 to a reference level of TED to 0 for the minimum level of development. For each country we calculated the growth rate of technical-economic activity over a five-year period. For each five-year period the calculation is based on the output values of the trained neural network Kohonen, reflecting changes in the level of energy in terms of absolute changes in macroeconomic and innovation indicators during this period.

**Table 1.** The category of countries, selected on the level and pace TED by neural networks modeling (2005–2010).

| **Group** | **Leaders of growth (> 4 %)** | **Countries with an average growth rate (2 – 4 %)** | **Countries with low growth rate (1 – 2 %)** |
|---|---|---|---|
| Leaders of TED | Canada | USA, UK, Italy, France, Germany | Japan |
| Developed countries | Ireland, Denmark, Sweden, Switzerland | Iceland, Slovenia | Austria, Belgium, Luxembourg, Netherlands |
| Countries with moderate levels of TED | India, Brazil, China, Russia, Cyprus, Estonia | Hungary, Lithuania, Poland, Portugal, Finland, Slovakia | Norway, Spain, Greece, Malta |
| Developing countries | Turkey, Bulgaria, Romania | Greece, Latvia | Croatia, Serbia |

In terms of global crisis, the canadian economy has demonstrated a high degree of stability, improving its position in the list of world leaders TED to GDP and investment attractiveness. Relatively high growth rates and energy consumption for the developed countries account activation business with effective state regulation and export growth. In addition, the canadian economy is very favorable to the proximity of the U.S. and various trade agreements such as the automotive agreement (1965–2001), canadian-American free trade agreement of 1989 (FTA) and the North American free trade agreement 1994 (NAFTA). GDP per capita (population of Canada is little more than 34.2 million people) in 2010 reached 45.9 thousand dollars. USA with stable consumer spending. In this regard, Canada is on par with the United States (47,1 $ thousand), but surpasses all other countries included in the "seven" leaders TED (Japan, UK, Germany, France and Italy).

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Among the developing countries among the growth leaders became Turkey – due to the low level of public debt and the banking system, not by the global financial crisis, Turkish companies will be able to benefit from the current low costs and competition in the manufacturing sector.

In total GDP Russia close behind Brazil. But most importantly, Russia is much closer to the level of the UK, Italy and France, behind them now within just 20 %, showing a higher growth rate TED. GDP per capita lags behind the US in 4 times, from Western Europe 3 times, from Canada and Japan - 3.1 - 3.3 times, from Germany - 3 times, from the UK, Italy and France less than 3 times, but ahead of Mexico 18%, Brazil - 22%, China -1.8 times, India - 3.2 times. Attention is drawn to the strong position of China. Chinese GDP already exceeds 60 % of the US GDP, and Japan's GDP is now only about half of China's GDP.

The calculation results for "actual distance" is presented in the Table 2.

**Table 2.** The category of countries, selected by the parameter "Actual distance" of neural networks modeling (2005-2010).

| The actual length | Country |
|---|---|
| < 10 years | Switzerland, Finland, Germany, Denmark, Sweden, UK |
| 10 – 20 years | Russia, Czech Republic, Greece, Malta, Portugal, Hungary, Lithuania, Bulgaria, Poland, Slovakia, Italy, Norway, Spain |
| > 20 years | Romania, Latvia, Turkey, Croatia |

Neural network analysis identifies the following indicators of the technical-economic growth, the significance level which exceeds 0.7 units (the GDP, the share in global GDP of major economies, the cost of consumption of primary raw materials (food, construction materials, fuel and energy resources), the volume of industrial production, total expenditure on research and development, the share of R & d expenditures in GDP, the index of quality of life, index of enrolment, people who have received an academic degree and higher education per 1,000 population aged 20 to 29 years, the share of research and development costs for the technology and medium-high level (% of manufacturing costs), expenditure on innovation (% of total turnover), the share of high tech exports in total exports, patents per million population and others).

Thus, the significance of the parameter "Total expenditure on R & d" is 0.83% In 2007 all world expenditure on R & d amounted to approximately 1.1 trillion dollars, including the U.S. share corresponded to approximately 33 % of total, Japan was ranked second among the countries in the world in R & d expenditures, its share is 13 %, China's share is about 9 %. Germany and France took fourth and fifth place with 6 and 4%, respectively, Russia - 1 %.

To achieve the reference level of energy among the main directions of social policy in relation to the income it would be advisable to include the development of complex of measures on improvement of quality of life as a factor of GDP growth, in particular and energy in general. Social policy should focus on achieving a high quality of human capital characteristics, variety and alternatives provided for opportunities for self-improvement, realization of creative potential, the ability of quick adaptation, versatility perception of the world, health and longevity.

## 5 Conclusion

On the basis of many national and international scientific research developed the technique of multi-criteria neural network measurement of the level and pace of global economic and technological development on complex quantitative and qualitative indicators. On the basis thereof a flexible neural network model of the trajectory of the global tehnical and economic development in the form of dynamic range cluster Kohonen maps with relatively simple but powerful strategy for improving the accuracy of clustering without prejudice interpretability, with evaluation of the level of TED, performance and TED consumption of individual countries and for forecasting future values of a multidimensional process. Their mapping on the reference and national trajectories TED allows to obtain a reliable assessment of not only speed, but also the level of technical and economic development of each country.

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