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Analytical Modeling and Genetic Algorithms in the Development of Adaptive Strategies for Optimizing Energy Efficiency of the Fuel and Energy Complex (Case of the Regions of China, Russia and India)

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ABSTRACT

This study is devoted to the development of an algorithm for analyzing and optimizing energy efficiency indicators in the fuel and energy complex (FEC) based on state statistics of the leading BRICS economies (China, Russia and India). The research methodology includes formalization of key factors influencing energy saving targets, construction of econometric models, cleaning variables from statistically insignificant factors and application of genetic algorithms to determine optimal parameters. The final optimization function implements mathematical formalization of the compromise between increasing energy efficiency targets and minimizing changes in input factors, which makes the results suitable for practical implementation. The algorithm provides solutions that minimize costs and ensure compliance with the specified constraints within the modeling framework. The final data are presented in the form of text reports and infographics, allowing for a detailed statistical and analytical review of the indicators by region of the countries considered. This aspect allows integrating the obtained results into the process of making economically sound strategic decisions aimed at modernizing and improving the efficiency of the energy sector. The developed approach is focused on current tasks of strategic management, including data systematization, development of long-term programs for modernization of the fuel and energy complex and increasing the sustainability of the energy system to external factors. The results obtained have a high degree of universality and can be applied to optimize individual processes within the energy sector and to develop national and interstate energy saving strategies.

INTRODUCTION

The fuel and energy complex (FEC) is a fundamental component of the socio-economic development of modern states, playing a decisive role in ensuring their economic stability and industrial growth. Growing energy consumption, increasing international competition and limited natural resources pose challenges for the energy sector that require an integrated approach, including increasing the efficiency of energy use, reducing dependence on imported equipment and technologies, and developing strategies to optimize energy consumption. The economic significance of the FEC is determined by its impact on macroeconomic indicators, such as GDP growth rates, energy independence, profitability of production processes and investment attractiveness of the industry. The introduction of innovative technologies, infrastructure modernization, digitalization of processes and the transition to renewable energy sources are becoming priority areas of strategic development, helping to reduce the energy intensity of the economy and improve its competitive position.

1 LITERATURE REVIEW

Research on the fuel and energy sector addresses a wide range of issues, including assessing its sustainability, risk management, and adaptation to modern economic challenges. For example, Orlova et al. and Ilyinykh et al. focus on risk insurance in the energy sector and the need for digitalization of processes (Orlova et al., 2018; Ilyinykh et al., 2023). The article Zhen Yang et al. analyzes the possibility of achieving simultaneous economic growth and environmental protection in China (Zhen Yang et al., 2022). Using night-light data and the environmental pressure index, the authors conduct a decomposition analysis, showing that a number of Chinese provinces have managed to achieve a "win-win" situation between economic development and reducing environmental impact. In particular, the article Qihang Feng et al. analyzes the sustainability of China's economic growth in the face of global challenges that affect economic development trajectories (Qihang Feng et al., 2024).

The review Zhencheng Fan et al. examines current advances in AI and DL and their application to achieve sustainable development goals, including in the field of renewable energy and building energy management (Zhencheng Fan et al., 2023). The study Kedong Yin et al. examines the impact of AI development on green technology innovation in China (Kedong Yin et al., 2023). Panel data analysis shows that AI contributes to the improvement of green technology efficiency, especially in western regions of China. The authors identify nonlinear threshold effects due to the intensity of environmental regulation and R&D investment. The study Tianhao Zhao et al. analyzes the relationship between green energy adoption, economic growth and innovation in OECD countries (Tianhao Zhao et al., 2024). Using a random forest model, the authors find that the transition to green energy has a significant impact on the human development index. The authors emphasize the importance of developing integrated approaches to efficiency assessment, including the use of analytical tools. At the same time, the environmental aspects of the fuel and energy complex, as noted in the study Pashkevich et al., require the development of methods for monitoring and preventing man-made risks (Pashkevich et al., 2006).

The impact of sanctions pressure on the modernization of the Russian fuel and energy complex is one of the topical research topics reflected in the works Dmitrievsky et al. and Lebedeva et al. (Dmitrievsky et al., 2016; Lebedeva et al., 2024). Scientific attention is focused on the tasks of import substitution and localization of production capacities, which contribute to strengthening technological independence and minimizing foreign economic risks. Within the framework of these studies, strategies for diversifying capital sources and developing national mechanisms for financial support of modernization projects are presented. One of the promising areas is the creation of algorithms for optimizing interactions between economic entities and counterparties in conditions of increased uncertainty of the market environment. For example, the study Zaytsev et al. proposes a game algorithm built on the basis of game theory, which uses indices of mutual influence and payment matrices (Zaytsev et al., 2024). The model is designed to increase the stability of interactions, minimize risks and form balanced cooperative and competitive strategies. The investment attractiveness of the energy sector, as emphasized Loktionov, should be assessed in terms of its impact on systemic stability, reducing the likelihood of power supply failures and increasing the efficiency of resource use, which requires the development of analytical approaches that take into account regional characteristics and institutional constraints (Loktionov, 2013).

The article Lagutenkov, A.A. et al. proposes a conceptual model of transition to a "green" economy, including stages from theoretical understanding to the introduction of practical implementation mechanisms (Lagutenkov, A.A. et al., 2022). The analysis focuses on the institutional and technological drivers that form the basis for environmentally oriented models of economic growth. Particular emphasis is placed on the importance of international cooperation and the adaptation of economic management strategies to national specifics. In particular, the study Jia et al. discusses the prospects for improving the energy efficiency and environmental sustainability of the Chinese steel industry in the context of tightening environmental requirements and growing international obligations (Jia et al., 2022). The application of an integrated approach to the analysis of the effectiveness of environmental initiatives is carried out through the study of the introduction of energy-efficient technologies and the modernization of technological processes. The authors present strategies that ensure a balance between achieving economic goals and reducing the environmental burden, and also propose mechanisms for integrating these solutions into national economic policy.

In recent years, the issues of increasing energy efficiency in the fuel and energy sector of various countries, including the BRICS states, have been actively studied in the international scientific literature. Research focuses on the development of mathematical models and optimization algorithms aimed at reducing energy consumption and reducing carbon dioxide emissions. For example, the work Dahir et al. analyzes the determinants of energy efficiency and their impact on environmental indicators in the BRICS countries (Dahir et al., 2022). The authors conclude that the integration of renewable energy sources and increased energy efficiency provide a significant reduction in the carbon footprint and improve environmental performance in the long term. This approach is of particular relevance in the context of managing the resource potential of regions, since it allows taking into account the relationships between socio-economic processes and energy parameters.

The article Zaytsev et al. develops a methodological approach to diagnosing the resource potential of regions, aimed at assessing their contribution to ensuring socio-economic development (Zaytsev et al., 2023). The study considers quantitative indicators of resource potential and their integration into the regional planning process. This approach allows formalizing the strategic aspects of energy resource management, taking into account regional and national characteristics. In another study Wang et al., an improved fuel efficiency optimization model based on fractional programming methods is proposed (Wang et al., 2023). The model is designed to minimize fuel consumption in power systems by optimally distributing the load between generators and energy storage systems. The results show that the use of this approach reduces both operating costs and overall energy consumption, improving the efficiency of power systems.

The use of analytical modeling and genetic algorithms is becoming an integral part of energy efficiency improvement strategies in the energy sector. In the study Nacef et al., a genetic algorithm is presented for selecting the optimal energy transmission route taking into account energy losses occurring during conversion and transportation (Nacef et al., 2023). The model demonstrates the ability to explore a multidimensional solution space while minimizing time and space costs, which improves the functional efficiency of smart grids and the energy internet. In another study Khan et al., a hybrid ensemble machine learning model combined with a genetic algorithm is proposed for the optimal selection of energy consumption forecasting parameters (Khan et al.,2020). This approach improves the accuracy of energy demand estimation and provides more efficient energy distribution management. The authors emphasize that the use of integrated approaches to forecasting helps to increase the sustainability of energy systems and minimize operational risks.

The work Zaytsev et al. analyzes the impact of resource potential on the sustainability of socio-economic development of regions, with an emphasis on energy security and reducing environmental risks (Zaytsev et al, 2023). The authors examine approaches to integrating strategic energy policy and environmental monitoring aimed at improving the efficiency of natural resource use. The study developed analytical models that allow formalizing resource management processes, which helps optimize their distribution and use. The study Zaytsev et al. examines the economic aspects of renewable energy development, including its importance for ensuring long-term energy independence and reducing the negative impact on the environment (Zaytsev et al, 2022). The authors conduct a quantitative analysis of the economic benefits and costs associated with the introduction of renewable energy technologies, assess their impact on restoring ecological balance and the sustainability of national economies. The model approach used in the work demonstrates the possibilities of an optimal combination of economic and environmental priorities in strategic planning.

Analysis of the fuel and energy complex requires consideration of macroeconomic, regional and institutional factors. The BRICS countries — China, Russia and India — present different approaches to the modernization of their energy systems, due to their unique resource base, national energy policy goals and specific economic models. In this context, the development of energy efficiency strategies involves the use of mathematical and econometric methods, including regression modeling and optimization algorithms. These approaches provide opportunities for a quantitative assessment of the influence of determining factors on energy saving indicators, as well as for the formation of scientifically based recommendations for improving their values.

The use of analytical tools, such as regression analysis, helps to identify dependencies between energy indicators and economic determinants. Optimization algorithms, including genetic and neural network methods, provide an opportunity to develop adaptive strategies for managing energy flows and minimize technological losses, which allows for the formation of flexible and efficient energy consumption models that can be integrated into strategic planning processes at the national and regional levels.

1.2 Purpose and direction of work

The aim of this study is to develop an algorithm for analyzing and optimizing the energy efficiency of the fuel and energy complex using mathematical modeling methods, which can be used to formulate long-term energy saving management strategies. The results of the work are aimed at integrating modern analytical approaches into the decision-making process aimed at increasing the competitiveness of the energy sector and ensuring sustainable economic growth. The object of the study is the processes of managing energy saving and energy efficiency in the fuel and energy complex, as well as economic and technological factors affecting their parameters. The subject of the study is mathematical models and algorithms for analyzing and optimizing the energy efficiency of the fuel and energy complex, including regression analysis methods, genetic algorithms and their practical application for forming energy sector management strategies.

2. RESEARCH METHODOLOGY

2.1 Analysis of the spectrum of the fuel and energy complex situation in the BRICS countries

Modern economies are faced with the task of comprehensively assessing the efficiency of the fuel and energy complex both at the national and regional levels. It is proposed to use the energy saving indicator as a universal efficiency indicator, which reflects the degree of optimal use of energy resources and their economic return. Energy saving forms the basis for reducing total costs in the energy sector. Optimization of energy consumption is achieved by reducing operating costs for the production and transportation of energy resources, which is becoming especially significant in the context of volatility in world oil and gas prices, as well as increased competition in global markets. In addition, the development of energy saving strategies is an integral part of strengthening energy security, as it reduces dependence on hydrocarbon production and equipment imports.

The implementation of energy saving programs serves as a driver for the introduction of innovative technologies and the modernization of technical infrastructure, contributing to an increase in the technological efficiency of the industry. For example, the use of smart grids and modern materials leads to a reduction in process losses, an increase in overall productivity and an improvement in the competitiveness of energy systems both domestically and internationally. Energy conservation has a significant impact on socio-economic development, as it increases the availability of energy in remote regions, which stimulates an improvement in the quality of life of the population, contributes to the modernization of infrastructure and creates new jobs associated with the introduction, operation and maintenance of energy-efficient technologies.

The growth of global energy consumption necessitates the development of energy conservation strategies, which become a tool for adapting to the challenges associated with increasing energy demand, changing resource availability and tightening international environmental standards. Energy conservation can be considered as an indicator of the maturity of the industry and its readiness to implement innovations, which determines the prospects for its long-term growth and sustainable operation. The economies of the BRICS countries (China, Russia, India) demonstrate a variety of approaches to the development of the fuel and energy complex, which is due to the historical, resource and economic characteristics of each state. These differences determine the specifics of national energy conservation strategies, which are aimed at achieving sustainability and efficiency of energy systems, taking into account local and global challenges. The key features of the energy systems of the BRICS countries are analyzed below, focusing on their institutional structure, economic models and strategies for increasing energy efficiency.

2.2 China: Centralized Control and Leadership in Energy Conservation

China is an example of a country where energy conservation has become a strategic direction of state policy (Table 1). The beginning of active development of the fuel and energy complex falls on the middle of the 20th century, when coal became the main source of energy. Since the 1990s, China has begun to modernize infrastructure, introduce energy-efficient technologies and actively develop renewable energy. The main focus was on reducing the energy intensity of the economy, which became one of the key factors of economic growth.

Table 1. Key Features of China's Energy Conservation Policy

Characteristics	*Description*
Centralized management	State-owned companies such as the State Grid Corporation play a leading role in implementing national energy conservation and infrastructure modernization strategies.
Implementation of innovative technologies	China is a world leader in the production and use of energy-efficient equipment, including smart grids and energy management systems.
Energy saving policy	The five-year plans are aimed at reducing the energy intensity of the economy, which is achieved through the introduction of technologies to improve the efficiency of energy production and transportation.

Source: own

Energy conservation in China has a significant impact on the economy, helping to reduce dependence on coal energy resources, reduce environmental impact and strengthen the country's position as a world leader in renewable energy. China's policy combines centralized management, technological innovation and long-term planning, which ensures a high degree of sustainability of the energy system and its adaptation to modern challenges.

The transition to energy-efficient technologies and the development of renewable energy sources reflects China's strategic focus on reducing the carbon footprint and increasing the sustainability of economic growth. The approaches used in China's energy sector demonstrate an example of a successful combination of management, technological and environmental solutions to achieve high efficiency in the fuel and energy sector.

2.3 Russia: Focus on hydrocarbon exports and slow modernization of the fuel and energy sector

The Russian fuel and energy complex is characterized by a historically established export focus and high dependence on hydrocarbon resources (Table 2). The Soviet legacy ensured the presence of a large-scale infrastructure, including an extensive pipeline network and large oil and gas fields. However, priority attention was given to the export of raw materials for a long time, which affected the low rate of implementation of energy-saving technologies.

Table 2. Main characteristics of the Russian fuel and energy complex

Characteristics	*Description*
Export focus	The main focus is on the extraction and transportation of hydrocarbons, which determines the energy intensity of the system and its dependence on world oil and gas prices.
Slow modernization	Despite the launch of energy saving programs, infrastructure modernization is complicated by its wear and tear, insufficient investment and a high level of dependence on hydrocarbons.
Energy saving in new projects	Innovative technologies aimed at reducing process losses and increasing energy efficiency are being introduced at Arctic fields such as Yamal LNG.

Source: own

Russia's energy policy focuses on improving energy efficiency and reducing process losses. Production process modernization programs are aimed at increasing the competitiveness of the energy sector and reducing the impact of external economic factors, such as sanctions and price fluctuations on world markets. Despite significant potential, Russia is still inferior to other major economic players in the field of energy conservation, which is explained by the high share of outdated technologies and the structural dependence of the fuel and energy complex on hydrocarbon resources. However, the gradual introduction of innovative solutions, such as energy-saving technologies in Arctic projects, can help strengthen the country's position in the energy sector. Energy projects aimed at increasing energy efficiency are becoming the basis for creating a sustainable energy system capable of meeting the challenges of the global economy and adapting to changes in international markets.

2.4 India: Growing Energy Demand and Need for Energy Conservation

India, being one of the most dynamically developing economies in the world, faces increasing energy demand due to population growth and industrial production scale (Table 3). The development of the country's fuel and energy complex is accompanied by challenges related to ensuring sustainable energy consumption and minimizing the negative impact on the environment. Energy conservation is a strategic task that integrates economic, technological and environmental aspects.

Table 3. Key Features of India's Power System

Characteristics	*Description*
Coal Dependency	The main source of energy is coal, which leads to high energy intensity of production and significant losses during production and transportation of energy resources.
Renewable Energy Development	Active investment in solar and wind energy aimed at reducing dependence on hydrocarbons and increasing energy efficiency.
Energy Saving Initiatives	Programs such as UJALA stimulate the mass adoption of energy-efficient technologies, such as LED lamps, and the modernization of the power grid to reduce losses.

Source: own

Energy conservation is an economic tool and a factor ensuring energy availability in regions with low electrification. Modernization of infrastructure, transition to renewable energy sources and development of intelligent energy management systems form the basis for increasing the technological efficiency of the energy sector. The programs implemented by the Government of India, such as improving energy infrastructure and stimulating the use of energy efficient solutions, help reduce the energy intensity of the economy and reduce environmental risks. The combination of economic incentives and technological innovations allows not only to meet the growing energy demand, but also to minimize costs and environmental costs. Thus, energy conservation in India is becoming an integral part of the strategic management of the energy sector, forming long-term prospects for the sustainable development of the national economy.

3. METHODOLOGY

3.1 The Importance of the Fuel and Energy Complex for Interethnic Cooperation Based on the BRICS Association

The fuel and energy sector plays a key role in the development of economic, political and strategic cooperation between the BRICS countries, which unite the world's largest developing economies: Brazil, Russia, India, China and South Africa. Energy cooperation allows countries to strengthen their positions in the international arena, develop strategies to improve energy security and ensure economic growth (Table 4).

Table 4. Key aspects of the importance of the fuel and energy sector within BRICS

Aspect	*Description*
Energy base for economic growth	Joint work in the energy sector helps countries meet the growing demand for energy needed for industrial production, transport and social security.
Resource diversity and complementarity	Each country has unique resources, which creates opportunities for synergy. For example, Russia is a major exporter of oil and gas, while India and China are active energy importers.
Promotion of energy efficiency and renewable energy sources	Joint efforts are aimed at developing energy efficiency standards, financing renewable energy projects and sharing advanced technologies.
Geopolitical significance	Coordination of actions in the fuel and energy sector allows countries to strengthen strategic positions, resist fluctuations in global energy prices and respond to sanctions pressure.
Energy conservation as a priority	Reducing the energy intensity of the BRICS economies through joint initiatives accelerates the implementation of energy efficient solutions, which is especially important for large economies such as Russia and China.
Investment cooperation	The fuel and energy sector is becoming a platform for attracting investment in projects, including cross-border infrastructure initiatives, energy transmission networks, resource extraction and processing.

Source: own

BRICS energy cooperation promotes the integration of technologies and knowledge, the development of long-term energy conservation strategies and the transition to more sustainable resource consumption models, which allows countries to minimize economic and environmental risks associated with fluctuations in global markets. BRICS energy cooperation should be aimed at further developing a systemic approach to energy resource management, strengthening the coordination of scientific research and the implementation of integration projects. Of particular importance are energy conservation initiatives that allow countries to efficiently allocate resources, minimize losses and strengthen energy independence. Thus, the fuel and energy complex within BRICS acts as a platform for the implementation of comprehensive initiatives aimed at ensuring sustainable growth, increasing competitiveness and strengthening positions in the global energy market. The authors of the study propose a methodology for determining key indicators from an array of all indicators presented in processed form on Internet resources (repositories) of official state statistics of the relevant BRICS countries. The convenience of the presented information, its openness and accessibility, as well as the scale of the economies and the degree of involvement in international projects determined the choice of China, Russia and India as the objects of the study.

The algorithm for determining the key indicators (indicators) of state statistics that have the greatest impact on the level of energy efficiency of the fuel and energy complex in the context of individual regions of the three largest BRICS economies is divided into several key stages:

- Determination of target indicators Y. This is carried out using expert assessments and auxiliary neural network tools. If such are available in the array of relevant state statistics, preference was given to direct components of the fuel and energy complex.
- Determination of five factors influencing each Y. Similarly, this is carried out using expert assessments and auxiliary neural network tools. Here, the possibilities for choosing indicators directly related to the fuel and energy complex are limited by the content of the statistical arrays, however, as already discussed above, the fuel and energy complex has a direct or indirect impact on a wide range of spheres and areas.
- Approximate estimate of the limits of annual growth of target indicators Y. This step is necessary for constructing mathematical models in subsequent stages. This step was carried out using the analysis of historical data and the opinions of subject observers. The list of target factors Y selected as a result of the first three steps with a country breakdown and the rationale for the approximate forecast is presented below.

3.2 China

China has demonstrated sustainable momentum in its energy sector, supported by long-term government strategies and infrastructure upgrades (Table 5). The focus on renewable energy and rural energy efficiency is helping to reduce the carbon footprint and promote economic diversification. Particular attention is paid to investments in upgrading power generation capacity and integrating modern technologies. Projected growth rates indicate continued focus on increasing productivity and optimizing the use of natural resources.

Table 5. Key indicators and forecasts for the development of China's energy system

Indicator	*2023 data*	*2024 Outlook*	*Annual growth limit*
Rural Electricity Consumption	Increased by 12.6% to 1.172 trillion kWh. Rural grid modernization continues and electric vehicle use grows.	Growth of 10-12%, driven by infrastructure development and renewable energy deployment.	12%
Installed Electric Power Capacity	Increased by 202.98 GW (to 2,922.24 GW), led by renewable energy (solar: +55.2%, wind: +20.7%).	Growth of 7-8% (200-230 GW), driven by ambitious renewable energy capacity expansion plans.	8%
Investments in Fixed Assets of the Electric Power Industry	Increased by 30.1% to RMB 967.5 billion. Modernization of energy infrastructure and transition to renewable energy.	Growth slowing to 10-15%, given a five-year plan that includes a 25% increase in investment in 2023-27.	15%
Investments in the Energy Sector	*Increased by 13% ($271 billion). Almost on par with OECD countries. Renewable energy sector growth.*	*Growth forecasted at 10-15%, driven by continued strong deployment of renewable energy.*	*15%*
Daily Tap Water Consumption Per Capita	*Stable (less than 610 billion cubic meters). Efficient use of water thanks to modern technologies.*	*Growth of 1-2%, driven by limited growth trends and water management measures.*	*2%*

Source: own

3.3 Russia

The energy system of Russia continues to demonstrate trends aimed at modernizing the infrastructure and improving the profitability of production. The main emphasis is on increasing investment in the energy sector, including renewable energy projects. However, high dependence on hydrocarbons and significant wear and tear of equipment limits the possibilities for a significant increase in energy efficiency (Table 6).

Investment policy aimed at modernizing energy facilities contributes to a gradual decrease in the energy intensity of the national economy. However, additional measures are needed to achieve long-term sustainability, including the development of programs to support innovative technologies and increased coordination between market participants. Russia, with its significant potential in the field of energy efficiency, is able to strengthen its position in the global energy market through the implementation of strategies aimed at reducing dependence on hydrocarbons and increasing the sustainability of the energy sector.

Table 6. Key indicators and forecasts for the development of the Russian energy system

Indicator	*Data for 2023*	*2024 Outlook*	*Annual growth limit*
Proportion of total area equipped with gas	The predominance of natural gas in electricity production is due to significant reserves and availability of the resource.	A slight increase in the share of gas-fired power plants due to constraints related to the development of renewable energy sources and modernization of capacities.	0.5%
Investments in fixed capital of electric power industry	Increase in capital investments related to infrastructure modernization and renewable energy development.	A growth of 5%, limited by high project implementation costs and economic uncertainty.	5%
Investments in fixed capital in general	Investment growth in Q3 2024 was 5.1%.	An average annual growth forecast is 4%, taking into account the impact of economic factors and market fluctuations.	4%
Provision of electricity to private property	Growth in the electrification of private homes and an increase in the number of households.	A moderate increase of 1%, limited by infrastructure and economic conditions.	1%
Profitability of electricity provision	The indicator, which depends on tariff policy and production costs, shows stable growth.	An increase of 2% due to measures to improve production efficiency and stable demand for electricity.	2%

Source: own

3.4 India

India, as one of the fastest growing economies, demonstrates a commitment to increasing production capacity and optimizing the employment structure of the population. Government incentive programs such as “Make in India” contribute to the creation of new jobs, modernization of industrial infrastructure and attraction of investments (Table 7). The growth in the number of households reflects the processes of urbanization, and the decrease in their average size is associated with changing social norms. These trends create demand for energy and infrastructure, stimulating the development of the energy sector. Economic and demographic indicators confirm India’s potential for sustainable development of its industrial and energy sectors, as well as the need to implement long-term strategies aimed at improving energy efficiency and ensuring energy security.

Table 7. Key indicators and forecasts for the development of industry and energy sector in India

Indicator	*2023 Data*	*2024 Forecast*	*Annual growth limit*
Number of factories (Y)	Sustained growth of 5-7% driven by industrial development and the Make in India initiative.	Expected to increase by 5-7% due to investment in the manufacturing sector and an 8-10% increase in steel demand.	7%
Distribution of employed population by industry	The indicator is changing slowly, growing by 1-2% per annum, depending on economic development and government policies.	Gradual increase of 1-2% due to changes in the structure of the economy and labor migration.	2%
Estimated number of households, average household size and sex ratio	The average household size is about 4.4 persons. There is an increase in the number of households by 1-2% per	Expected increase in the number of households by 1-2% and a gradual decrease in the average household size.	2%

	annum, while their average size is declining by 0.5-1%.		
Employment rate of population (WPR)	The employment-to-population ratio (WPR) for persons above 15 years was 58.2%, an increase of 2.2 percentage points compared to the previous year.	Projected growth of 2-3 percentage points depending on educational programs and employment initiatives.	3%
Net regional product at current prices (NSDP)	Real GDP growth was 8.2%. Adjusted for inflation, nominal growth could be higher.	Expected growth of 10-12% due to consumer spending and investment activity.	12%

Source: own

4. ANALYTICAL MODELING

After defining the growth boundaries of the target parameters Y, as well as after compiling five analytical datasets with data from state statistics on certain indicators for all three BRICS countries selected for the study, the analytical modeling stage begins. For each row corresponding to one state/region/province of one of the countries, represented by one target indicator Y and 3-5 indicators X, a linear regression model is built, which expresses the dependence of the target variable (energy saving indicator) on factors X1, X2, ..., Xn, the process continues with the optimization of the factor values using a genetic algorithm. For each data row (region or province), a linear regression model is built:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon, \quad (1)$$

Where Y is the target variable reflecting the level of energy efficiency;

X1,X2,...,Xn are the factors influencing YYY;
β0,β1,...,βn are the regression coefficients;
ε is the random error distributed normally (ε~N(0,σ2).

After estimating the regression parameters using the least squares method, the target variable is expressed through the predicted function:

$$Y_{\text{predicted}} = \widehat{\beta_0} + \widehat{\beta_1} X_1 + \widehat{\beta_2} X_2 + \dots + \widehat{\beta_n} X_n, (2)$$

The next stage is optimization of the obtained models. It begins with clearing the model of parameters with low statistical significance (p-value > 0.1), until no more than four X factors remain. This is necessary to facilitate modeling by eliminating the least significant factors. As the main optimization parameter, an original metric is proposed, derived as follows:

For each observation (data row), optimization of factors is aimed at:

A. Minimizing changes in factors:

$$\Delta X = \sum_{i=1}^{n} \left| X_i^{new} - X_i^{original} \right|, \qquad (3)$$

where X_i^{new} — is the optimized value of the factor, X_i^{original} — is its initial value.

B. Maximization of the growth of the target variable Y, provided that:

$$\mathrm{Y_{optimized}} \leq \text{coef\_of\_rise} \cdot \mathrm{Y_{original}}, (4)$$

where coef_of_rise – is the obtained coefficient of the estimated annual growth of Y.

C. Satisfaction of constraints on factors X equal to the absolute minimum and maximum of the indicator in the sample:

$$X_i^{\min} \leq X_i \leq X_i^{\max}, (5)$$

Thus, the objective function of the genetic algorithm takes the form:

$$F(\mathrm{X}) = \frac{\Delta Y}{\lambda \cdot \Delta X}, (6)$$

where $\Delta Y = \left|\mathrm{Y}_{\mathrm{optimized}} - \mathrm{Y}_{\mathrm{original}}\right|$ — change of target variable;

λ — coefficient that controls the effect of changes in factors on the fitness value.

The analysis of the objective function $F(X)$ reveals several fundamental aspects that determine its significance in the process of optimizing energy efficiency parameters.

First, the value of ΔY reflects how significantly the algorithm managed to increase the initial target indicator. Maximizing the growth of the target variable is a key goal, since it determines the main meaning of optimization - improving the studied parameter (efficiency, energy saving of the fuel and energy complex).

Second, the presence of the multiplier λ and dependence on ΔX ensures a balance between aggressive improvement of the target indicator and minimizing changes in input factors. The introduced coefficient λ plays the role of a strictness regulator, which allows the model to manage the trade-off between the maximum benefit and the degree of adjustment of the initial conditions. If λ is small, then it is possible to achieve large improvements in ΔY at the cost of a significant restructuring of the factors. If λ is increased, the algorithm will have to be “more careful” about changes, trying to find a more delicate option for improving the target indicator with minimal corrections.

Thirdly, the final function shows not just a local improvement, but rather the effectiveness of intervention in the system. If we imagine that factors X act as controlled parameters of a technological process or economic policy, then ΔX characterizes the “costs” or “efforts” required to achieve the result ΔY. Thus, F(X) can be interpreted as a certain indicator of the “profitability” of changes: how many units of the target increase do we get for one unit of deviation of the factors.

Fourthly, when analyzing the final function, it becomes possible to assess the sensitivity of the system to changes in factors. A high value of F(X) will indicate that relatively small changes in factors lead to a significant increase in the target parameter. A low value indicates that even significant corrections of factor variables give only an insignificant increase, which may indicate the need to revise the selected model or optimization parameters.

Finally, it should be emphasized that the final function in this context becomes a tool not only for choosing optimal options for changes, but also for the subsequent analysis of the sustainability and effectiveness of the decisions made. By considering the obtained values of F(X) in combination with the constraints on the factors, the researcher can determine the ranges of acceptable changes, assess the system's limits, and understand under what conditions the optimal balance between the goal (improving energy efficiency Y) and cost (changes in X) is achieved.

4.1 Genetic algorithm

The use of a genetic algorithm is a key stage of optimization aimed at maximizing energy saving targets while minimizing changes in factors. The algorithm combines analytical modeling and evolutionary search methods to find the optimal balance between the system's goals and the constraints set by economic, physical and technological frameworks.

Algorithm operation stages:

A. Initialization of the initial population:

– Generation of the initial population of individuals: $\mathrm{X}^{(\mathrm{j})} = \{x_1^{(j)}, x_2^{(j)}, \dots, x_n^{(j)}\}$, where j=1,2,...,N, a N — population size.

– Each value $X_i^{(j)}$ generated randomly within acceptable limits $\left[X_i^{\mathrm{min}}, X_i^{\mathrm{max}}\right]$ by adding random noise.

B. Evaluation of individuals:

– For each individual, the objective function is calculated$F\left(\mathrm{X}^{(\mathrm{j})}\right)$.

– The predicted value of the target variable is calculated $Y_{\mathrm{predicted}}$ using the equation:

$$Y_{\text{predicted}} = \widehat{\beta_0} + \sum_{i=1}^{n} \widehat{\beta_i} X_i^{(j)}, (7)$$

– The fulfillment of the constraints on the growth of the target variable is checked:

$$Y_{\text{optimized}} \leq \text{coef\_of\_rise} \cdot Y_{\text{original}}, (8)$$

– The changes in the factors ΔX and the target variable ΔY are calculated.

C. Genetic algorithm operators:

- Selection: The tournament method is used to select individuals with the highest values $F(X^{(j)})$.
- Recombination (crossover): New offspring are created by linear combination of parent individuals:

$$X_i^{\text{new}} = \alpha X_i^{(j_1)} + (1-\alpha) X_i^{(j_2)}, \quad \text{where } \alpha \in [0,1], (9)$$

Mutation: For each offspring, a random change is added with a given probability:

$$X_i^{\text{new}} = X_i^{\text{new}} + \delta, \quad \text{where } \delta \sim \mathcal{U}(-\eta, \eta), (10)$$

where η — mutation parameter.

Limit Check: Values Out of Bounds $X_i^{\text{new}} \in [X_i^{\min}, X_i^{\max}]$, are brought to the nearest acceptable limit.

D. Iterations:

- The process is repeated for a given number of generations. At each step, the population is updated, optimizing the values of the factors.
- After the iterations are completed, the individual with the maximum value of F(X) is selected, which represents the optimized solution.

The final optimization problem is thus represented as:

$$max(Y_k) \frac{|Y_0 - Y_k|}{\lambda \cdot \sum_{i=1}^{n} \left| X_i^{\text{optimized}} - X_i^{\text{original}} \right|}, (11)$$

Subject to restrictions:

$$X_i^{\min} \leq X_i \leq X_i^{\max}; Y_{\text{optimized}} \leq \text{coef\_of\_rise} \cdot Y_{\text{original}}; \ Y_{\text{optimized}} \geq 0.$$

The final function formalizes the mathematical assessment of the relationship between the increase in target indicators (ΔY) and the adjustments of factors (ΔX). It serves as a tool for analyzing the efficiency and profitability of the changes made, providing a quantitative expression of the optimality of the achieved results. Considered as a metric of the profitability of adjustments, the function allows us to determine the most effective transformation strategies in terms of minimizing costs and maximizing results.

The increase in target indicators calculated on the basis of the proposed optimization function strictly corresponds to the realistic constraints formulated for the energy systems of the fuel and energy complex. The developed algorithm generates text and graphical analytical materials intended for practical use in the strategic planning process. These materials contain data on possible improvements and the benefits associated with them, which contributes to more informed decisions in the field of increasing energy efficiency.

The applied approach is highly adaptable and takes into account the specific features of the functioning of energy systems, which creates a solid foundation for improving analytical tools and further developing optimization methodologies. The developed algorithm includes two key stages: building a regression model and using a genetic algorithm. At the first stage, a linear regression model is formed that reflects the quantitative dependence of the target variable on the factors, which allows identifying the most significant factors and providing a mathematical description of the relationships in the system. The results of the regression analysis serve as the basis for the next stage.

At the second stage, a genetic algorithm is used to find optimal values of the factors. Constraints associated with physical, economic and technological parameters are taken into account. The algorithm is aimed at minimizing adjustments to the factors, provided that a significant increase in the target variable is achieved. This approach is especially effective for complex systems with multiple constraints.
The output data of the algorithm include:

- Optimized values of factors and targets representing balanced solutions.
- Information on changes for each observation (region, state or province).
- Full statistical data of the regression model for interpreting the results and analyzing the influence of factors.

The use of the algorithm facilitates informed management decision-making, minimizes risks and ensures the feasibility of proposed changes. The integration of analytical and optimization approaches makes the algorithm a universal tool for strategic planning in the field of energy saving and improving the efficiency of the fuel and energy complex.

The algorithm facilitates the development of management decisions based on detailed analytical and optimization approaches, minimizing risks and ensuring consistency of changes with the realities of the target system. The presented methodological tool has significant potential in strategic planning of complex systems, including addressing issues related to improving energy efficiency in the fuel and energy complex of the BRICS economies.

The final and intermediate results of modeling are generated using an automated cycle based on cascading command calls to a locally deployed neural network of the open-source Mistral_7B model. For each optimized model and its results, detailed text reports are created, supplemented by graphical analytics. The reports present data in various formats, including tables, charts and graphs, which ensures ease of interpretation and decision-making based on the information provided. Figure 1 shows the complete structure of the process – from identifying factors X that affect energy saving indicators Y to generating the final report. This diagram illustrates the stages of the algorithm's operation, including data preparation, building regression models, applying the genetic algorithm for optimization, and creating results suitable for practical use.

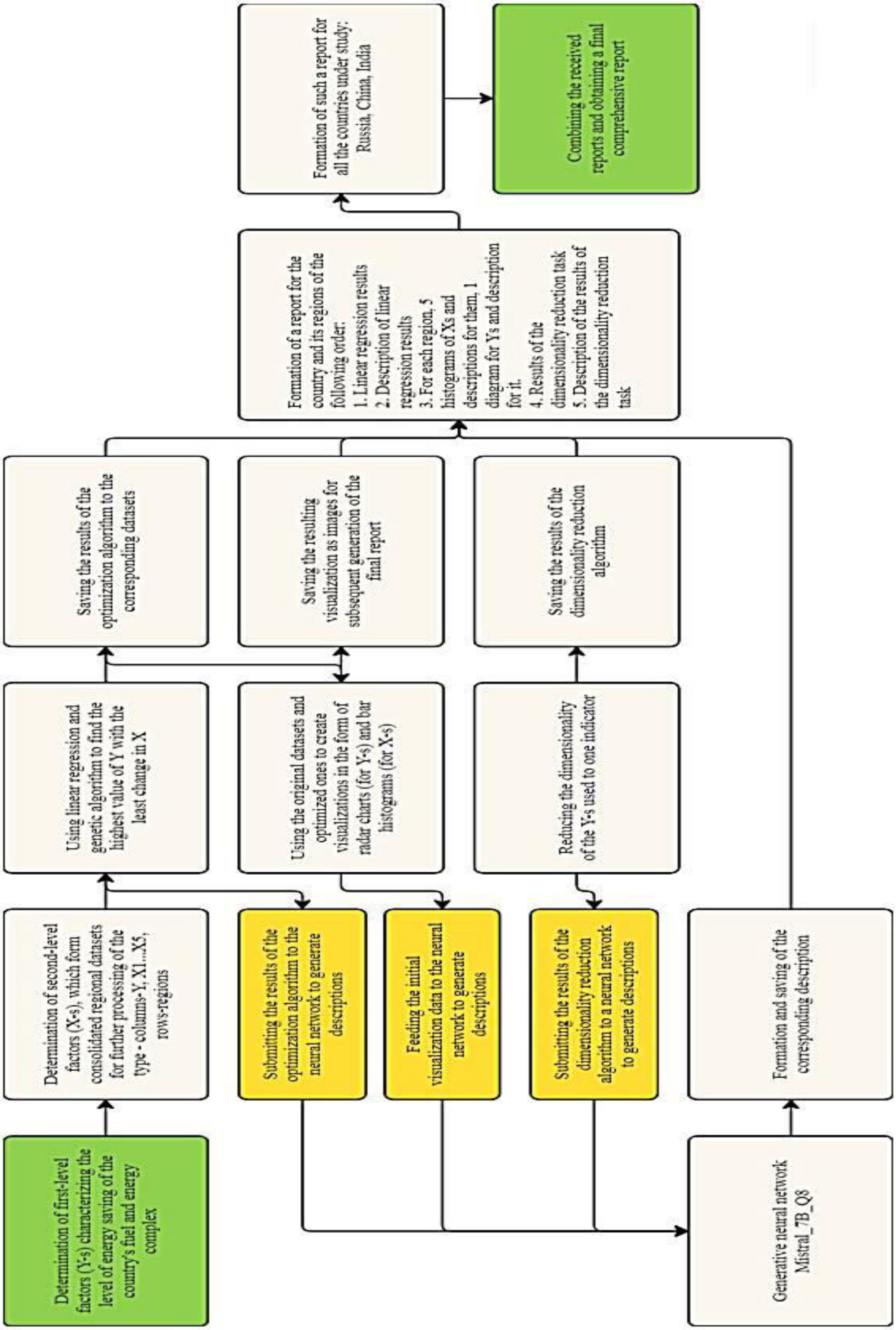

Figure 1. Block diagram of the full cycle of the developed algorithm
Source: own

The proposed algorithm can be adapted to specific conditions of the fuel and energy complex operation, taking into account regional and industry specifics. Its application allows for the formation of balanced management strategies aimed at achieving significant improvements in energy efficiency with minimal deviations from the initial conditions. Thus, this approach opens up new prospects for improving the efficiency of the fuel and energy complex operation in the conditions of the modern economic environment.

CONCLUSION

The conducted research is based on the study of the key role of the fuel and energy sector in ensuring economic growth and social development, especially within the largest BRICS economies: China, Russia and India. Global challenges such as increasing energy consumption, limited natural resources, as well as sanctions pressure and changes in global energy markets, require a strategic approach to improving energy efficiency. An analysis of the national strategies of the BRICS countries demonstrated the difference in approaches due to unique economic conditions and the structure of the resource base. China invests significant resources in the development of renewable energy sources and the introduction of innovative technologies, which helps reduce the energy intensity of the economy and strengthen its leadership position in the global market. Russia, focused on hydrocarbon exports, is taking steps to modernize infrastructure and improve energy efficiency, especially within the framework of new Arctic projects. India, seeking to meet the growing demand for energy, focuses on the development of renewable energy and providing electricity to all segments of the population, which is important for its industrial growth

The methodology for assessing the efficiency of the fuel and energy complex proposed in the work, based on the use of the energy saving indicator, includes several successive stages aimed at systematizing and optimizing processes:

- Determination of target indicators (Y). Based on expert assessments and neural network tools, key indicators related to the efficiency of the fuel and energy complex were identified.
- Determination of influencing factors (X). Indicators that have a significant impact on target parameters were identified. A wide range of data reflecting the impact of the fuel and energy complex on related industries was used in the accounting process.
- Forecasting growth boundaries. Based on the analysis of historical data and expert opinions, projected annual growth boundaries for target indicators were established.
- Analytical modeling. Linear regression models were built describing the dependence of target indicators on factors, with subsequent optimization of parameters using a genetic algorithm.
- Optimization. The use of a genetic algorithm allowed us to determine the optimal values of factors, minimizing deviations from the initial conditions and maximizing the growth of target indicators.

The modeling results showed significant potential for increasing the energy efficiency of the fuel and energy complex while maintaining minimal changes in factors, which confirms the need for a strategic approach to planning. The data obtained demonstrate the high efficiency of integrating analytical and optimization tools in the decision-making process at the level of public policy and interstate cooperation.

Thus, the developed approach meets modern challenges, providing a comprehensive toolkit for analyzing and optimizing energy saving in the fuel and energy complex. Its implementation contributes to achieving sustainable development of the energy sector and creating long-term strategies for increasing the competitiveness of the fuel and energy complex at the national and international levels.

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