10.63550/ICEIP.2026.79.19.049

Algorithmic Modeling and Forecasting of Innovative Development of Regional Systems in the Context of the Implementation of a Smart Economy

Salima Aleksandrovna Makhosheva[1] a, Zalina Khusenovna Gergova[2] b
[1]*Institute of Informatics and Regional Management Problems of the KBSC RAS, Inessa Armand st. 37 "a", Nalchik, Russia*
[2]*Kabardino-Balkarian State University named after V.I. HM. Berbekov, Chernyshevsky st., 173, Nalchik, Russia*
salima@list.ru

Keywords: innovative development, smart economy, digitalization, regional innovation system, forecasting, algorithms, development management.

Abstract: This article examines theoretical and practical approaches to developing algorithms for forecasting innovative development in the context of the emergence of a smart economy at the regional level. Particular attention is paid to modeling digital transformations of industries and their impact on the innovative potential of regional systems. Based on an analysis of the implementation of digital technologies and advanced management practices, algorithms for restructuring industries aimed at increasing the resilience and competitiveness of regional economies are proposed. The results of the study can be used by government agencies and research centers to improve innovative development strategies.

1 INTRODUCTION

In the context of the accelerated digital transformation of the global economy, the importance of innovative regional development as a key factor in sustainability, competitiveness, and socioeconomic balance is growing. The concept of a smart economy reflects the transition from traditional industrial models to economic systems based on knowledge, digital technologies, and intelligent data management.

The foundation of a smart economy is digital infrastructure, innovative ecosystems, human capital, and the ability of regions to adapt to technological shifts. These components form a new development paradigm in which data and knowledge act as strategic resources.

For Russia, this transition requires a comprehensive restructuring of regional economic systems. This transformation requires the development of new forecasting algorithms that take into account not only current macroeconomic parameters but also indicators of digitalization, innovation, sustainability, and management effectiveness.

Particular attention is paid to regions that are actively developing their innovative potential, where digitalization of production and management processes opens up new opportunities for growth.

One such region is the Kabardino-Balkarian Republic (KBR), a constituent entity of the Russian Federation within the North Caucasus Federal District. Despite its relatively modest starting position in innovation development rankings, the region is demonstrating positive dynamics in a number of key areas, including increased investment in digital infrastructure, expansion of IT services, the implementation of precision agriculture technologies, and the increasing role of educational institutions in training personnel for innovative industries.

According to HSE data (Innovative Development Ranking of Russian Regions, 2023), Kabardino-Balkaria is among regions with an emerging innovation system, characterized by scientific and

[a] https://orcid.org/0000-0003-4249-9906
[b] https://orcid.org/0000-0002-8332-8209

educational potential but limited access to investment resources and infrastructure support. However, in recent years, there has been a gradual increase in the values of specific indices related to socioeconomic conditions, digital employment, and export activity.

According to the statistical data book "Kabardino-Balkaria in Figures, 2024," fixed capital investment in 2023 exceeded 84.3 billion rubles, 6.2% higher than the previous year. Growth was observed in industry, construction, agriculture, and services. The share of companies using digital technologies in production process management, particularly document automation, digital logistics, and analytical platforms, is increasing. All of this creates the foundation for the formation of a digital model for regional development.

However, the transition to a smart economy is impossible without scientifically based forecasting approaches. Modern regional analysis models require consideration of multi-component factors—from digital infrastructure to human capital, scientific publications, patent activity, energy efficiency, and export potential.

In this regard, there is a need to develop algorithms and forecasting models capable of comprehensively assessing innovation dynamics and identifying areas for targeted impact on economic sectors.

Innovative regional development in today's environment is the result of the interaction of three fundamental components: technological potential, organizational and management mechanisms, and human capital. Only their systematic integration can create the conditions for sustainable growth and digital breakthrough. For the Kabardino-Balkarian Republic, where structural imbalances between industries and a low density of innovative enterprises persist, the algorithmization of management processes is becoming a key strategic planning tool.

The formation of a regional smart economy involves the implementation of digital governance principles and the use of big data (Big Data) for decision-making, the development of digital services, and increased digital literacy among the population. This creates the preconditions for a transition from intuitive to algorithmic innovation management, where every element of the system—from municipalities to enterprises—is integrated into a unified digital environment.

The challenge of innovation forecasting in regional systems lies in the need to account for differences between the economic structures of the Russian Federation's constituent entities. While large industrial regions are characterized by high investment capacity and developed infrastructure, institutional and personnel factors, including government support and the educational activities of the population, play a significant role in the republics of the North Caucasus.

Thus, for the KBR, a key focus is the creation of an intelligent management model capable of combining disparate data and forming a holistic picture of innovation potential.

The development of such models involves the use of modern analytical methods—correlation-regression models, neural networks, machine learning algorithms, and time-series forecasting. These approaches allow not only to assess current trends but also to forecast the dynamics of innovative development through 2030, as well as to identify the most promising industries for digital transformation.

An important element of the study is an assessment of the digital maturity of the region's industries, which will help identify areas requiring priority modernization. In industry, this includes automation and the implementation of production cycle management systems; in agriculture, the use of agro- IoT , soil monitoring, and drones; and in the service sector, the transition to platform business models and the development of e-commerce.

At the same time, there is a growing need to rethink the role of the state in the innovation process. Regional government bodies must shift from administrative to analytical management based on digital indicators and forecasting algorithms. This will minimize subjective factors and improve the accuracy of assessing the effectiveness of innovation policy.

Given limited resources and intense interregional competition, the Kabardino-Balkarian Republic must develop an innovative specialization strategy focused on its comparative advantages—agricultural production, tourism, processing industry, and educational and research centers. Their integration into digital ecosystems creates the preconditions for the formation of regional innovation clusters.

The implementation of these tasks requires a systematic approach and clearly defined research objectives.

The aim of the study is to develop algorithms and models for forecasting the dynamics of innovative development of a regional system in the context of the implementation of a smart economy using the example of the Kabardino-Balkarian Republic.

To achieve this goal, the following tasks are solved:

To analyze the current state and dynamics of digital technology implementation in the socio-

economic system of the Kabardino-Balkarian Republic and determine its level of digital maturity and innovative activity.

To identify key factors influencing innovative development and digital transformation of industries, including investment in fixed assets, human capital development, infrastructure, education, and institutional mechanisms for supporting innovation.

Develop algorithms for forecasting and adapting industries to digital transformation, allowing us to assess the readiness of industries to implement smart economy technologies and calculate probabilistic scenarios for innovative growth.

Develop a model for forecasting a region's innovative potential based on intelligent data analysis methods, including neural network algorithms and regression models, integrated with indicators from the innovation development rating and regional statistics.

Thus, the introduction forms the scientific and methodological basis of the study, substantiates its relevance and indicates the direction of further analysis related to the development of an algorithmic model for forecasting the innovative development of the Kabardino-Balkarian Republic in the context of the transition to a smart economy.

2 THEORETICAL FOUNDATIONS OF INNOVATIVE DEVELOPMENT

The modern development of the global economy is driven by digitalization, knowledge globalization, and the transition to a new type of economic system based on innovation. The concept of an innovative economy emerged from a transformation in understanding of production, where the key factors have shifted from physical resources to knowledge, information, and human creativity. An innovative economy is a system in which growth is driven by the constant creation, dissemination, and commercialization of new knowledge, technologies, and organizational solutions. It is characterized by a high degree of adaptability, the intellectualization of labor, and the active involvement of the scientific and educational sector in economic processes.

The transition from an industrial to an innovative economy reflects a shift in technological paradigms and development management strategies. While the industrial model was based on mechanization and standardization, the innovative economy is built on constant change, flexibility, and the ability to self-renew. Its development is underpinned by elements such as scientific research, the education system, the entrepreneurial environment, innovative infrastructure, and government support. Central to this model is the individual as the bearer of knowledge and competencies, who forms intellectual capital.

The concept of an innovative economy evolved into the idea of a smart economy—an intelligent, knowledge-based business model based on digital platforms, automation, and big data analysis. The smart economy integrates advances in information and communications technology (ICT), artificial intelligence (AI), the Internet of Things (IoT), machine learning, and blockchain to improve the efficiency of all socioeconomic processes. Its distinctive features include high manageability, transparency, and the ability to self-regulate based on real-time data processing algorithms.

In the context of regional development, a smart economy represents more than just the digitalization of individual industries, but a systemic transformation of the management model, where decisions are made based on analytical data and predictive algorithms. For Russian regions, including the Kabardino-Balkarian Republic, this concept is becoming key to improving resource efficiency, modernizing production facilities, and creating conditions for innovative growth. A smart economy enables the creation of an intelligent infrastructure that unites government, corporate, and scientific institutions into a unified digital ecosystem.

The theoretical basis for forecasting innovative development is a set of methods and algorithms aimed at assessing the dynamics of innovation processes, identifying patterns, and constructing scenarios for the future state of the system. Several approaches to innovation forecasting have been identified in the scientific literature. The first is indicative, based on statistical analysis of key indicators (GRP, patents, R&D, the share of innovative enterprises). The second is algorithmic, using mathematical models, neural networks, and machine learning to identify hidden relationships between innovation system parameters. The third is scenario-based, which involves the development of alternative development scenarios ("inertial," "innovative," and "breakthrough").

Within the framework of algorithmic approaches, forecasting models based on artificial intelligence are of particular importance. Neural networks, support vector machines, decision trees, and ensemble algorithms (Random Forest , Gradient Boosting methods enable the creation of accurate predictive models that account for nonlinear relationships between economic and technological factors. These methods are used to assess the likelihood of innovative breakthroughs, forecast investment

activity, and optimize management decisions. Their application in regional economics facilitates the transition from static forecasts to adaptive management systems that respond to changes in the external environment.

The theoretical basis of algorithmic forecasting is closely linked to the concept of a digital twin of a region (Digital Twin), which allows for the simulation of territorial economic development in a virtual environment. This approach is used to evaluate innovation implementation scenarios, test management decisions, and minimize risks. The creation of a digital twin of the Kabardino-Balkarian Republic could form the basis for the development of an intelligent strategic planning platform that integrates statistical data, spatial models, and forecast indicators.

International experience confirms the effectiveness of implementing a smart economy as a driver of sustainable growth. The European Union is implementing the Smart program. Specialization Strategy (S3), aimed at identifying regional competitive advantages and developing innovation clusters. As part of S3, EU regions are creating intelligent monitoring platforms that combine data on science, business, and infrastructure. For example, Finland has successfully integrated artificial intelligence algorithms into public services, and Estonia has become a global leader in digital governance and online services.

In Asian countries—South Korea, Singapore, and China—the digital transformation of regions is accompanied by the active development of innovative infrastructure and government support for technology entrepreneurship. Singapore has a national Smart concept. Nation , which envisions the complete digitalization of the economy and society, and in South Korea, the K- Smart system unites industry, universities, and government agencies into a single innovation network. The Chinese Digital Model China is focused on the large-scale application of artificial intelligence algorithms to manage the economy, forecast demand, and allocate resources sustainably.

Experience from other countries shows that the successful implementation of a smart economy requires a combination of three elements: technological infrastructure, human capital, and institutional coordination. These principles are universal and applicable to Russian regions, including the Kabardino-Balkarian Republic, where the formation of an innovative development model should be based on the adaptation of international practices to national conditions.

Thus, the theoretical foundations of innovative and smart development are based on a synthesis of economic, digital, and managerial concepts. Algorithmic forecasting methods serve as a tool for improving the effectiveness of regional policy, enabling the quantitative assessment of innovative potential and predicting its growth trajectories. For the Kabardino-Balkarian Republic, which is actively implementing digital technologies, these approaches provide the foundation for the transition from a declarative to a managed innovation strategy integrated into the nationwide smart economy system.

3 RESEARCH METHODOLOGY

The methodological framework of the study is based on a combination of principles of systemic, structural, and algorithmic approaches to analyzing the innovative development of regional systems. The empirical base was formed by data from official statistics and analytical sources—primarily the Innovation Development Ranking of the Subjects of the Russian Federation (HSE, 2023) and the statistical digest "Kabardino-Balkarian Republic in Figures, 2024" (Rosstat, 2024). These sources provide a comprehensive understanding of socioeconomic conditions, innovative activity, the level of digitalization, and the effectiveness of regional governance.

The study is comprehensive and relies on a combination of quantitative and qualitative analytical methods (Blokhin A.A., 2022; Schiuma G., Lerro A. 2008). This approach allows us not only to identify the current state of the region's innovation system but also to identify key areas for its development. The following methods are used in the study:

- comparative analysis - to identify differences between the Kabardino-Balkarian Republic and other subjects of the Russian Federation in terms of innovative development indicators;
- trend analysis aimed at determining the dynamics of socio-economic and innovation indicators for the period 2018–2023;
- correlation-regression modeling to assess the relationships between the levels of digitalization, innovation activity and economic growth (Linnenluecke M., 2022);
- cluster analysis, which allows grouping Russian regions according to their level of innovation potential and degree of readiness for the transition to a smart economy (Novikov D.A., et al., 2022).

The comparative analysis is based on comparing the Kabardino-Balkarian Republic with regions with

similar socioeconomic conditions and industrial structures. The analysis covers indicators of enterprise innovation activity, the share of domestic R&D expenditures, the level of digitalization of the economy, and institutional support for innovation (Shcherbachenko P.S., 2024). The results of the comparative analysis allow us to determine the KBR's place in the national innovation system and identify its competitive advantages and limitations.

Trend analysis is used to identify trends in key indicators: gross regional product (GRP), fixed capital investment, employment in knowledge-intensive industries, volume of shipped innovative products, and the share of digital technologies in industry (Rosstat, 2024). Based on these trends, forecast series are constructed, reflecting the trajectory of a region's innovative growth. The use of second- and third-order trend equations allows for increased forecast accuracy and the identification of medium-term trends through 2030 (Fedorov K.I., Fedorova S.V., 2022).

Correlation-regression modeling is used to assess the relationships between key parameters of a region's innovative development. The following indicators are used for analysis:

X_1 — the level of digitalization of the economy (the share of enterprises using ICT, %);

X_2 — investments in fixed capital (in billion rubles);

X_3 — the share of people employed in knowledge-intensive and high-tech industries (%);

X_4 — number of patents and applications for inventions (units);

X_5 — labor productivity index;

X_6 — the share of enterprises implementing technological innovations (%).

The dependent variable Y describes the region's innovation index, which characterizes the overall state of the innovation system. The regression model is as follows (Fedorov K.I. , Fedorova S.V., 2022):

$$Y=a_0+a_1X_1+a_2X_2+a_3X_3+a_4X_4+a_5X_5+a_6X_6+\varepsilon, \quad (1)$$

where a_i are the regression coefficients reflecting the degree of influence of factors, and ε is the random error.

Based on the calculated parameters, a forecast is made of changes in the region's innovation index depending on the dynamics of digitalization and investment.

To improve forecast accuracy, a cluster approach was used to divide Russian regions into groups based on similar innovation profiles (OECD, 2020; HSE, 2023). The k-means method is used for classification, comparing the Kabardino-Balkarian Republic with regions similar in GRP size and economic structure (the Karachay-Cherkess Republic, the Republic of Dagestan, and the Republic of North Ossetia-Alania). The clustering results allow us to determine whether the KBR's innovation system is emerging or developing, as well as its potential for transitioning to a smart economy.

To provide an integrated assessment of the level of innovative development, a forecast index of innovative development (PIR) is calculated based on the normalization of individual indicators and their weighting by significance (Vederin I.V. et al., 2022). The formula is as follows:

$$PIR = \sum_{i=1}^{n} w_i * \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (2)$$

where w_i are the weighting coefficients of the indicators reflecting their contribution to innovative development;

X_i — actual value of the indicator;

X_{min}, X_{max} are the minimum and maximum values for the sample of regions.

The resulting index ranges from 0 to 1 and allows for ranking the region by its level of innovation activity.

The construction of the forecast index of innovative development of the region (PIR) is based on the dynamics for 2018–2023 with subsequent extrapolation to 2030. The forecast values are calculated using the time series function (Mazhorina M.V., 2021):

$$PIR_t=\alpha+\beta_1 t+\beta_2 t^2+\varepsilon_t, \quad (3)$$

where t is the time period, and α and βi are the trend parameters. This allows us to model three development scenarios: inertial (growth less than 2% per year), innovative (3–5%), and breakthrough (6–8%).

Thus, the applied methodology combines traditional statistical methods with modern algorithmic data analysis tools. The use of comparative, trend, regression, and cluster approaches allows not only for a quantitative assessment of the innovative potential of the Kabardino-Balkarian Republic but also for the construction of a predictive model , Smart Model - KBR, designed to forecast the dynamics of the region's innovative development in the context of digital transformation and the implementation of smart economy principles (Burganov O.V., et al., 2023).

4 RESULTS AND DISCUSSION

The current state of innovative development in the Kabardino-Balkarian Republic (KBR) is determined by a combination of factors related to the level of digitalization, the state of scientific and technological potential, and the effectiveness of governance institutions. According to the National Research University Higher School of Economics (HSE Innovative Development Ranking of Russian Federation Regions, 2023), Kabardino-Balkaria ranks 61st out of 85 regions and is classified as having an emerging innovation system (HSE, 2023). This means that while the region does have some elements of an innovative infrastructure, they do not provide a systemic effect on the economy. However, over the past five years, there has been a steady positive trend across most indicators, indicating a gradual strengthening of the innovation ecosystem.

Table 1: Key indicators of innovative and digital development of the Kabardino-Balkarian Republic (2018–2023).

Indicator	2018	2020	2021	2022	2023	Change 2023 to 2018, %
Gross regional product (billion rubles)	166,4	186,7	202,1	221,5	238,9	+43,6
Investments in fixed assets (billion rubles)	58,7	66,2	74,5	79,4	84,3	+43,6
The share of innovatively active enterprises, %	6,1	7,2	7,9	8,3	8,8	+44,2
Internal R&D expenditure (RUB million)	515	592	635	701	753	+46,2
Number of patent applications (units)	54	61	63	69	72	+33,3
Share of people employed in knowledge-intensive and high-tech industries, %	3,5	4,0	4,2	4,5	4,8	+37,1
Use of ICT by organizations, % of total	68,0	72,4	74,2	77,1	79,5	+17,0
Digital maturity level of government bodies (index, scores from 0 to 1)	0,54	0,61	0,65	0,69	0,73	+35,2
Share of population with digital skills, %	62,3	65,5	67,1	68,8	70,9	+13,8
Export of innovative products (million rubles)	401	444	497	521	545	+35,9
Integral index of innovative development (0–1)	0,29	0,33	0,36	0,38	0,41	+41,4

The HSE ranking includes five blocks characterizing the level of innovative development of a region:

- socio-economic conditions;
- scientific and technical potential;
- innovative activity;
- export activity;
- quality of innovation policy.

In each of these areas, the Kabardino-Balkarian Republic demonstrates heterogeneous results, which allows us to identify both competitive advantages and structural constraints.

1. Socio-economic conditions

In the “socio-economic conditions” block, the KBR ranks 56th among the constituent entities of the Russian Federation (HSE University, 2023).

The key growth factors were the increase in GRP by 43.6% in 2018–2023 (from 166.4 to 238.9 billion rubles) and the growth of investment in fixed assets by 43.6% (from 58.7 to 84.3 billion rubles) (Rosstat, 2024).

A positive demographic trend is emerging in the region: the share of the working-age population is approximately 58%, which is higher than the average for the North Caucasus Federal District.

The infrastructure for supporting small and medium-sized businesses is developing, and the share of those employed in the service sector has reached 54.7%.

However, structural imbalances between industry and the agricultural sector persist: the share of the processing industry in GRP does not exceed 10%, which limits the potential for technological renewal of the economy.

2. Scientific and technical potential

According to the indicator “scientific and technical potential”, the Kabardino-Balkarian Republic ranks 63rd (HSE University, 2023).

Despite the relatively small scale of scientific research, there has been a steady increase in internal

R&D expenditures—from RUB 515 million in 2018 to RUB 753 million in 2023 (+46.2%).

The key centers of scientific activity are the Kabardino-Balkarian State University, the Institute of Applied Research of the Kabardino-Balkarian Scientific Center of the Russian Academy of Sciences, and agricultural research structures.

Patent activity is growing: the number of applications for inventions increased from 54 to 72, primarily in the fields of energy, agriculture, and medical technology.

However, in terms of the number of researchers per 10,000 employed people, the KBR lags behind the Russian average by almost half, indicating the need to expand the human resources base and attract young specialists to the field of science and technology.

3. Innovative activity

In the “innovation activity” block, Kabardino-Balkaria demonstrates a significant improvement – from 72nd to 59th place (HSE University, 2023).

The share of innovatively active enterprises increased from 6.1% to 8.8%.

The most active sectors are agricultural processing, food industry, education and IT.

Enterprise participation in federal NTI support programs is expanding, in particular through the Skolkovo and Start (Foundation for Assistance to Small Innovative Enterprises) foundations.

At the same time, the share of innovative products in the total volume of shipped industrial products remains low – less than 2.5%, which limits the overall contribution of innovation to the region’s economy.

There is a shortage of private investment in innovative projects, and the public sector continues to play the main role in their financing.

4. Export activity

The "export activity" block is rated as one of the weakest for the region. The Kabardino-Balkarian Republic ranks 65th (HSE University, 2023).

The volume of innovative product exports increased from 401 million rubles in 2018 to 545 million rubles in 2023 (+35.9%), but the share of high-tech exports does not exceed 1.5%.

The main export directions remain agricultural products and processed food products.

Limited diversification of the export structure and low integration into international innovation networks hinder growth potential.

However, in recent years, the region has been developing the conditions for entering digital solutions markets in the fields of education, tourism, and agricultural technology.

5. Quality of innovation policy

In the “quality of innovation policy” block, Kabardino-Balkaria is in 58th place (HSE University, 2023).

The region is actively implementing government support measures for innovation and digital activities.

In 2023, the "Strategy for the Socioeconomic Development of the Kabardino-Balkarian Republic until 2035" was approved, with digital transformation highlighted as a separate area.

The "My Business" and "Digital Economy of the KBR" centers have been established, and subsidy programs for IT companies are in place.

The most significant progress has been made in the area of digital public administration: the digital maturity index of government bodies increased from 0.54 to 0.73.

However, experts note insufficient coordination between scientific institutions, enterprises and the regional administration, as well as the weak development of mechanisms for assessing the effectiveness of innovative projects (Shcherbachenko P.S. , 2024).

Dynamics of GRP, investment and employment in knowledge-intensive industries

According to Rosstat data (Rosstat, 2024), in 2018–2023, the volume of the KBR’s GRP increased from 166.4 to 238.9 billion rubles, which corresponds to an average annual growth of 6.1%.

Investments in fixed assets increased to 84.3 billion rubles (+43.6%).

The share of people employed in knowledge-intensive industries reached 4.8%, which is higher than the average for the North Caucasus Federal District (4.2%).

The employment structure is gradually shifting towards services, education, and IT, forming the basis for the development of the digital economy.

However, there remains a high dependence on budgetary investments, the share of which exceeded 42% in 2023, indicating the need to stimulate private capital and innovative entrepreneurship.

Strengths and weaknesses of the KBR innovation system. Strengths:

- positive dynamics of socio-economic indicators;
- growth of digital infrastructure and government maturity index;
- development of research centers and increase in patent activity;
- a high proportion of the population with digital competencies;
- availability of strategic digital development programs.

Weaknesses:

- insufficient integration of science and business;

- low share of innovative products in industry;
- weak export and venture activity;
- lack of private investment in R&D;
- personnel gap in engineering and IT areas.

Thus, the Kabardino-Balkarian Republic demonstrates a stable trend towards strengthening its innovative potential while maintaining a number of institutional and infrastructural limitations.

In general, the region is characterized by a transition from the initial stage of innovative development to the stage of an emerging innovative system, which creates the preconditions for the construction of the Smart Model -KBR - an algorithmic model for forecasting innovative development integrated into the concept of the smart economy.

Modern approaches to managing regional innovative development require a shift from declarative strategies to formalized forecasting models based on data processing algorithms and intelligent analysis methods. For the Kabardino-Balkarian Republic, which is currently developing its innovation system, such a model is becoming a tool for integrating digital, institutional, and socioeconomic factors into a unified analytical framework. Therefore, this study proposes the concept of Smart Model - KBR—an adaptive hybrid model for forecasting the dynamics of regional innovative development.

Conceptually, the Smart Model - KBR is built on the principles of a smart economy, where knowledge, digital technologies, and intelligent management algorithms are key development resources. The model combines traditional econometric approaches and modern machine learning methods, allowing it to account for both linear relationships between macroeconomic indicators and nonlinear interactions between digitalization, investment, and human capital factors. Unlike static models, the Smart Model - KBR is a dynamic system that adapts to updated statistical data and changing political and economic conditions.

The model is based on the assumption that the innovative development of a region is determined by the combined influence of the following key factors:

Dt — level of digitalization (share of organizations using ICT; digital maturity index of government bodies).

It — investment in fixed capital (billion rubles or growth rate).

Ht — human capital (the share of the population with digital skills, the number of STEM graduates per 1000 people).

Rt — internal R&D costs (million rubles).

Pt — patent activity (number of applications).

Gt — quality of innovation policy/institutional index (availability of strategies, “My Business” centers, subsidies).

S_t^k — sectoral indicators for industry k (agriculture , industry , services): technological advancement, share of exports in the section, digital maturity of the sector.

These indicators form a system of input variables reflecting the economic, technological, and institutional components of the innovation environment. The model's target variable is the integrated innovation development index (*PIRT*), calculated based on normalized data from the Innovation Development Ranking of Russian Federation Subjects (HSE, 2023) and official Rosstat statistics (2024).

The mathematical structure of the Smart - Model -KBR is presented as an autoregressive model with exogenous variables (ARX model), which allows for describing the dynamics of the innovation development index, taking into account the influence of both current and past factor values. The basic equation is:

$$PIR_t = \phi_0 + \phi_1 PIR_{t-1} + \sum_{\in\{D,I,H,R,P,G\}} \beta_i X_{i,t} + \gamma Z_t + \varepsilon_t \quad (4)$$

Where

$X_{i,t}$ — normalized inputs D_t, I_t, H_t, R_t, P_t, G_t;

Z_t — denotes the set of external influences (government support measures, macroeconomic shocks)vector , bonuses, subsidies, federal injections);

ϕ_1 – autodependency coefficient ;

ε_t — stochastic error of the model.

Thus, the model combines the principles of classical econometric analysis with the ability to forecast using dynamic time series.

To improve the prediction accuracy, the residuals (ε_t) are estimated using machine learning algorithms such as Random Forest or gradient boosting , which allows to correct for nonlinear and interacting effects between variables.

$$\hat{\varepsilon}_t \approx M_\theta(X_t, \Delta X_{t-1:t-3}, \text{soft indicators}) \quad (5)$$

The final forecast is formed according to the following scheme:

$$\widehat{PIR_t} = \widehat{PIR_t}^{(ARX)} + \widehat{\varepsilon_t}^{(ML)} \quad (6)$$

where the first component reflects the trend component of development, and the second – adaptive adjustments due to artificial intelligence.

The process of constructing a Smart Model - KBR includes several sequential stages.

The first stage involves collecting and structuring data from open sources (HSE, Rosstat, and regional economic development departments). Next, the data is preprocessed: cleansed, normalized, and deleting.

At the second stage, the econometric part of the model (ARX) is constructed, which allows us to identify the main direction of change in the innovation development index.

In the third stage, machine learning of the residuals is performed to take into account complex relationships between factors that are not captured by traditional regression methods.

At the final stage, scenario modeling is performed, where various development trajectories for the region are defined by changing key parameters (investments, digitalization, personnel policy, etc.).

Thus, the model functions as a self-correcting mechanism, capable of adapting to new information. The advantage of this approach is the ability to integrate qualitative expert assessments (e.g., of policy measures or strategies) into a quantitative forecasting model.

To assess potential trajectories for innovative development in the Kabardino-Balkarian Republic, three scenarios were constructed: inertial, innovative, and breakthrough. The KBR's 2023 innovation development index of 0.41 was adopted as the baseline (HSE University, 2023).

The business-as-usual scenario assumes the current pace of digitalization and investment activity continues. The average annual growth rate of the index is estimated at 2%, which would lead to a $PIR_{(2030)}$ value of ≈ 0.47. This scenario reflects weak institutional change and limited private sector contribution.

The innovation scenario is characterized by the active implementation of digital technologies and increased investment in R&D. With an average growth rate of 4% per year by 2030, the $PIR_{(2030)}$ is projected to be ≈ 0.54, corresponding to the region's transition to the category of "developing innovation systems."

The breakthrough scenario is based on the assumption of large-scale government support measures, the development of innovative infrastructure, the implementation of digital education programs, and the formation of venture funds. In this case, the annual growth rate could reach 7%, with a projected $PIR_{(2030)} \approx 0.66$, bringing Kabardino-Balkaria closer to the level of strong innovative regions in Russia.

The results of the scenario analysis demonstrate the model's high sensitivity to investment and personnel factors. Thus, a 1% increase in R&D spending potentially increases the overall innovation development index by 0.012 points, while a 5% increase in digital inclusion of the population increases the index by 0.008 points.

Model accuracy is assessed using standard metrics—R^2, RMSE, and MAPE—to enable objective comparison of different approaches. A rolling window method is used to prevent overfitting . window validation) and cross-validation over time series. It should be noted that the limitations of Smart - Model -KBR are related to the quality of regional statistics, the endogeneity of several variables (for example, investment simultaneously depends on innovation potential), and the likelihood of short-term shocks not accounted for by the model.

The application of the Smart Model -KBR in management practice allows regional authorities and analytical centers of the KBR to assess the consequences of decisions and forecast the dynamics of innovative development. Based on the model, it is possible to create annual "innovation progress maps" reflecting the contribution of digitalization, investments, and educational initiatives to the overall development index.

It is recommended to implement the Smart Model -KBR as an element of the regional digital platform "Digital Economy of the KBR" and integrate it with monitoring data from the Ministry of Economic Development of the Russian Federation. This will ensure the transition from declarative strategies to data - driven decisions. policy), corresponding to the principles of smart economy.

Thus, the developed Smart Model - KBR represents a universal tool for analyzing and forecasting the region's innovation dynamics. Its hybrid structure combines the scientific rigor of econometric analysis with the adaptability of machine learning. The model's application allows not only for quantitatively assessing the effectiveness of innovation policy but also for identifying priority areas for targeted intervention—investment, digital infrastructure, human resources, and innovation export. For the Kabardino-Balkarian Republic, this model serves as a methodological basis for formulating a strategy for transitioning to a sustainable smart economy by 2030.

Current digital transformation trends point to the need to create a sustainable innovation ecosystem, in which the development of digital infrastructure,

educational centers, and networking between business, science, and government play a key role. For the Kabardino-Balkarian Republic (KBR), which possesses significant human potential and a growing scientific and technological foundation, these areas are becoming strategic priorities.

One of the most important vectors of development is the creation of a developed digital infrastructure that provides high-speed Internet access, the introduction of cloud technologies, platform solutions and big data systems (Big Data). This will significantly improve the efficiency of regional process management, reduce transaction costs, and ensure transparent interactions between government agencies, businesses, and citizens. Regional data processing centers (DPCs) and intelligent platforms for analyzing socioeconomic indicators should become an important element of the digital economy infrastructure .

The second area is related to the development of an education and training system focused on the digital and innovative economy. The creation of specialized educational centers, artificial intelligence laboratories (AI Labs), and retraining programs in digital technologies will provide the region with the necessary competencies. Collaboration between universities and technology parks with real-world enterprises—the so-called Triple Model—plays a key role in this process. Helix (university-business-state), which has proven its effectiveness in EU countries and South Korea (OECD, 2020).

A third promising area is the integration of artificial intelligence (AI), the Internet of Things (IoT) , and big data analysis into regional governance systems. The use of AI and predictive algorithms in monitoring socioeconomic processes will enable the creation of dynamic models of industry development, forecasting growth points, and assessing the effectiveness of management decisions in real time. The use of Big Data and IoT in urban and agricultural management are particularly relevant for the Kabardino-Balkarian Republic, where territorial and climatic conditions require highly adaptable infrastructure solutions.

An equally significant area is the creation of innovation clusters and technology parks , which facilitate the concentration of scientific, educational, and entrepreneurial resources. The establishment of such centers in Nalchik, Baksan, and Prokhladny will unite small innovative enterprises, start-ups, and research institutes within a single technological development space. Cluster development has shown that the concentration of high-tech companies in a single region contributes to increased innovation rates and enhanced competitiveness (Sciuma G., Lerro A., 2008).

The development and implementation of a regional smart economy strategy through 2030 is becoming a key strategic focus . It should define targets for increasing the innovation development index, the digital maturity of government agencies, and the share of high-tech sectors in the GRP. Such a strategy should be based on the principles of sustainability, data openness, and the integration of science, technology, and entrepreneurship. It could serve as a foundation for the development of a new data-driven model of public administration. governance , in which decision-making is based on a comprehensive analysis of large amounts of information.

Implementing these initiatives will enable the Kabardino-Balkarian Republic not only to achieve sustainable innovative growth but also to become a model for integrating smart economy principles into regional practice. This requires ensuring institutional support for initiatives, developing venture capital financing, improving the regulatory framework, and implementing digital project management tools.

5 CONCLUSION

The study demonstrated that the Kabardino-Balkarian Republic possesses sustainable preconditions for the development of a regional innovation system aligned with smart economy principles. An analysis of the innovative development rankings of Russian regions (HSE, 2023) and Rosstat data (2024) revealed that the region is in the process of establishing its innovation infrastructure, demonstrating positive dynamics in key areas: increased investment, increased digital maturity of government agencies, expansion of educational programs, and increased scientific research.

Smart - Model -KBR model developed as part of the study allowed us to generate quantitative scenarios for the region's innovative development through 2030. According to calculations, under the business-as-usual scenario , the KBR's innovation development index will increase from 0.41 to 0.47; under the innovative scenario, to 0.54; and under the breakthrough scenario , to 0.66. These indicators reflect possible growth trajectories depending on the intensity of digital technology implementation, human capital development, and institutional transformation.

The analysis confirms that the region's innovative development is highly dependent on the volume of

investment in R&D, the level of digitalization, and the effectiveness of public administration mechanisms. Given limited resources and intense competition between regions, these factors are crucial for achieving sustainable growth. In particular, increasing investment in R&D, developing IT infrastructure, and stimulating innovative entrepreneurship could accelerate the innovation index by 5–7% annually, allowing the KBR to move into the category of regions with a developed innovation system.

The practical significance of this study lies in the fact that the proposed algorithms and the Smart - Model -KBR forecasting model can be used by executive authorities in Kabardino-Balkaria when developing socioeconomic development strategies, digital transformation programs, and innovation policies. Furthermore, the study's results are of interest to universities, research centers, and businesses involved in the creation of regional innovation clusters.

Thus, the analysis and modeling resulted in scientifically based recommendations for improving the KBR's innovation policy, aimed at integrating smart economy principles, developing human capital, and building digital infrastructure. These measures create the preconditions for sustainable and balanced innovative growth in the region through 2030.

REFERENCES

Blokhin, A.A., 2022. Digital transformation of regional innovation systems: theory and practice. *- M.: Finance and Statistics. - 214 p.*

Burgonov, O.V., Golubetskaya, N.P., Chirkova, T.V., 2023. Theoretical and practical approaches to the implementation of ESG principles in the management of Russian companies*. Problems of Modern Economics. No. 2. P. 115-121.*

Vederin, I.V., 2022. ESG: Three letters that change the world. *Moscow: HSE Publishing House. 138 p.*

Kabardino-Balkarian Republic in numbers: brief statistics*. Sat. Nalchik: KBRstat , 2024. — 140 p.*

Majorina, M.V., 2021. ESG principles in international business and "sustainable contracts". *Current issues of Russian law. Vol. 16, No. 12. P. 185-198.*

Novikov, D.A., Khorolskaya, T.E., Voronova, S.M., 2022. Socially oriented management of business structures based on ESG criteria. *Natural Sciences and Humanities Research. No. 44 (6). P. 457-462.*

Innovative Development Rating of the Subjects of the Russian Federation: Issue 11 / edited by L.M. Gokhberg. 2023. *Moscow: National Research University Higher School of Economics, 260 p.*

Fedorov, K.I., Fedorova, S.V. 2022. Practice of ESG-transformation of business: results, measurement, development vectors. *Economic vector. No. 2 (29). - P. 126-138.*

Shcherbachenko, P.S., 2024. ESG transformation of business and region. *Bulletin of Eurasian Science. Vol. 16. - No. S6.*

Berg, F., Kölbel, J.F., Rigobon, R., 2022. Aggregate Confusion: The Divergence of ESG Ratings. *Review of Finance. Vol. 26, Issue 6. P. 1315–1344.*

Linnenluecke, M., 2022. Environmental, Social and Governance (ESG) Performance in the Context of Multinational Business Research. *Multinational Business Review.*

OECD. 2020. Regions and Innovation Policy: Smart Specialisation in Global Context. *Paris: OECD Publishing.*

Schiuma, G., Lerro, A., 2008. Knowledge-based capital in building regional innovation capacity. *International Journal of Innovation and Regional Development. Vol. 1, No.1. P. 111–133.*