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MODELLING OF NATIONAL ECONOMIC DEVELOPMENT IN THE CONTEXT OF ENSURING SUSTAINABLE DEVELOPMENT AND HUMAN CAPITAL PROGRESS

ABSTRACT

The sustainable development of a national economy is a central concept in modern public governance, aiming to ensure a balanced interplay between economic growth, social equity, and environmental sustainability. This study seeks to develop theoretical and methodological approaches, alongside practical tools, for modelling and forecasting sustainable economic development. Particular attention is given to the role of human capital as a critical driver that enhances labour productivity, innovation capacity, and resource efficiency. The article highlights key challenges in implementing sustainable development models: the lack of integrated modelling frameworks, insufficient and low-quality data, the pace of global change, the absence of clear methodologies, and limited innovation activity. An econometric model is constructed to evaluate the impact of sustainability components on GDP as a core macroeconomic indicator. The model incorporates economic, social, and environmental variables, emphasizing human capital as a mediating factor. Two-variable trend analyses are used to explore relationships between real GDP and selected indicators. The study identifies the most influential factors as the Consumer Price Index (%), State Budget Deficit (UAH million), Minimum Wage (UAH), Share of Renewable Energy in Total Supply (%), and Energy Consumption from Wind and Solar Sources (thousand tons of oil equivalent). Correlation and determination coefficients are calculated to quantify these relationships. GDP forecasting is conducted using logarithmic, exponential, and power regression models. Based on the findings, the paper outlines strategic directions for promoting sustainable development in Ukraine, focusing on economic, environmental, and social dimensions through the advancement of human capital. The research methodology combines a systemic and interdisciplinary approach, employing tools such as comprehensive factor analysis, strategic planning, and econometric modelling using the Data Analysis and Regression toolkit.

Keywords: sustainable development, economic and mathematical modelling, economic growth, components of sustainable development of the national economy, human capital

JEL Classification: C50, E22, F02

INTRODUCTION

In the current conditions of globalization and growing environmental challenges, sustainable development is one of the most important priorities for any country. Accurate modelling and forecasting of a nation's sustainable development enable the achievement of a balanced integration of economic growth, social welfare, and environmental sustainability.

The problem of combining sustainable development goals with active human capital development remains understudied in domestic econometric modelling. The lack of a unified analytical framework complicates forecasting the long-term development of the national economy.

The relevance of this topic is due to:

- economic challenges: the world is experiencing increasing market instability, which necessitates the creation of economic models that take into account long-term sustainability. Modern forecasting methods allow us to assess the impact of political decisions and resource constraints on future economic development;
- environmental factors: depletion of natural resources, climate change and environmental pollution require the integration of environmental indicators into economic models. This contributes to the development of effective strategies for the transition to a "green" economy;
- social aspects: sustainable development encompasses equal access to opportunities, enhancement of living standards, and the reduction of social disparities. Modelling such processes helps to focus on the implementation of policies aimed at the well-being of people;
- global obligations: Ukraine, like most countries in the world, has joined the implementation of the UN Sustainable Development Goals. This requires a clear understanding and planning of ways to achieve them, which is possible thanks to modelling and forecasting;
- innovative technologies: the development of artificial intelligence methods, Big Data and other digital tools opens up new opportunities for improving economic modelling. They allow the creation of more accurate forecasts and adaptive strategies.

Modelling and forecasting sustainable development can offer valuable instruments for efficient economic management amid ongoing change.

LITERATURE REVIEW

The sustainable development of the national economy and the advancement of human capital have been extensively explored in numerous studies by both domestic and international scholars.

The deepening of research in the field of modelling sustainable development of the national economy and human capital progress has been reflected in a number of scientific works that emphasize the relationship between environmental sustainability, social investment and economic efficiency. For example, Redko K. and Miroshnychenko V. conducted a comparative analysis of sustainable development indicators of Ukraine, Germany and Poland, comparing them with the target benchmarks set by the UN (Redko & Miroshnychenko, 2022). In the study of Panchyshyn T. and Vdovyn M., the multidimensional ranking method was applied to assess regional sustainable development, which allowed taking into account both stimulating and restraining factors (Panchyshyn & Vdovyn, 2023). A significant contribution to the mathematical substantiation of sustainable development mechanisms was made by Skoruk O., proposing the use of models at the enterprise level (Skoruk, 2024). In the context of the digital transformation of the economy, Kondratenko N., Papp V., Romanyuk M., Ivanova O. and Petrashko L. focused on the role of digitalization in stimulating regional development (Kondratenko, Papp, Romanyuk, Ivanova & Petrashko, 2022). Some aspects of organizational support for sustainable development are highlighted in the work of Fadeeva I., Orlova N., and Makarova V., which modelled business processes in the context of the globalization of the green economy (Fadeeva, Orlova & Makarova, 2023). Spatial approaches to the analysis of the sustainability of Ukrainian regions were implemented in the study of Zomchak L. and Koval L., who used spatial autoregressive models and spatial error models (Zomchak & Koval, 2022). Budnikevich I. and colleagues applied cluster analysis to determine typologies of regions by the level of sustainable development (Budnikevich, Kolomytseva et al., 2021). Ugur Korkut Pata examined the impact of renewable energy consumption, ICT development, and human capital on achieving the Sustainable Development Goals in the long term (Ugur Korkut Pata, 2025). An in-depth study of the relationship between energy, social and environmental determinants of development was carried out by Kanwal N., Ihsan H., Irum S. and Ambrin I., who analyzed the short- and long-term relationships between human and physical capital, emissions, urbanization and economic growth (Kanwal, Ihsan, Irum & Ambrin, 2024). Plaksiuk O. et al. substantiated the importance of investments in science and education as key factors in strengthening human capital, which directly affects national socio-economic development (Plaksiuk et al. 2023).

Despite the significant amount of research devoted to the sustainable development of economic systems, the issue of modelling and forecasting the sustainable development of the national economy requires further research for several key reasons:

1. The dynamism of the global environment: the conditions in which the national economy operates are constantly changing due to globalization, climate change, innovation and geopolitical challenges. Conventional models often lack the flexibility to adequately reflect the pace of these rapid changes.

2. The interplay between social, economic, and environmental dimensions: sustainable development involves a balance between economic growth, social well-being and the conservation of natural resources. However, creating models that effectively integrate these aspects is a complex task that requires innovative approaches.
3. The lack of localized data: for effective forecasting, detailed data adapted to a specific national economy are required. Insufficient availability or quality of such data may complicate the development of accurate models.
4. Development of technologies and modelling methods: new methods such as machine learning, big data and artificial intelligence open up new opportunities for predicting sustainable development, but their integration into economic models is still in its early stages.
5. The need for long-term planning: most models focus on short-term forecasts, while sustainable development requires a long-term vision that takes into account future challenges and risks.
6. The ambiguity of the concept of sustainable development: sustainable development has different interpretations depending on the context. This creates a need for more adaptive and clear models that take into account the specifics of each country.

Future studies will facilitate the creation of more precise, flexible, and applicable models that support the efficient management of economic, social, and environmental resources in pursuit of sustainable development.

AIMS AND OBJECTIVES

The aim of the study is to establish theoretical and methodological frameworks, along with practical guidelines, for modelling and forecasting the sustainable development of the national economy, which ensure a harmonious balance between economic growth, social justice and environmental sustainability, with special attention to the progress of human capital as a key factor that contributes to increasing the effectiveness of all components of sustainable development.

The objectives of the study are:

- to identify the key challenges within the concept of sustainable development of the national economy, particularly in relation to the advancement of human capital;
- to explore the interconnections between the economic, social, and environmental dimensions of sustainable development, with a focus on the evolution of human capital;
- to develop an econometric model that examines the impact of sustainable development components on GDP, the primary macroeconomic indicator of national economic performance, while considering human capital's role as a crucial factor influencing labour productivity, innovation capacity, and resource efficiency. Additionally, to conduct an in-depth analysis by constructing trend lines for a two-factor analysis of independent variables and real GDP;
- to calculate GDP forecast values based on various factors influencing the sustainable development of the national economy in light of human capital progress;
- to outline strategic directions for the development of the national economy, focusing on ensuring sustainable development and the advancement of human capital in economic, environmental, and social dimensions.

METHODS

For effective analysis, forecasting and management of sustainable development processes, various modelling methods are used that allow taking into account economic, social and environmental aspects. These methods range from classical statistical approaches to modern artificial intelligence algorithms. This study used econometric models based on quantitative analysis of relationships between key indicators of sustainable development: analysis of cause-and-effect relationships between variables, and assessment of the elasticity of indicators.

The method for identifying the key challenges within the concept of sustainable development of the national economy, considering the progress of human capital, involves a thorough analysis of macroeconomic indicators, investments in education and healthcare, environmental and social factors, regional disparities, and resource accessibility. This approach enables the identification of key limitations and obstacles hindering sustainable economic growth and the effective development of human capital.

The method for examining the interrelationship between the economic, social, and environmental components of sustainable development within the context of human capital evolution involves applying systems analysis and econometric models to assess the interaction between these components, in particular through the influence of the innovation and investment component of economic growth, social stability and environmental sustainability.

To develop an econometric model that assesses the impact of sustainable development components on GDP, the primary macroeconomic indicator of national economic performance, while considering the role of human capital as a critical factor influencing labour productivity, innovation potential and resource efficiency, as well as for the purpose of conducting in-depth analysis, as well as constructing a trend line in a two-factor analysis of independent variables and real GDP, the Data Analysis package tools and the Regression function, in particular, were used.

To define the development directions of the national economy in terms of ensuring sustainable development and advancing human capital across economic, environmental, and social dimensions, the following research methods were applied:

1. Systems analysis – to identify the interconnections between the economic, social, and environmental aspects of sustainable development and their influence on human capital.
2. Analysis of influencing factors - to study specific economic, environmental and social factors that contribute to or hinder progress in the development of human capital.
3. Strategic planning - to determine promising directions of development of the national economy and human capital, taking into account long-term trends.
4. Interdisciplinary approach - to integrate knowledge from various fields (economics, ecology, sociology) for a comprehensive analysis and development of effective strategies for sustainable development.

RESULTS

Sustainable development of the national economy, within the framework of human capital advancement, is a central concept in contemporary public administration, focused on achieving an equilibrium between social stability, environmental sustainability and economic growth. However, the implementation of this concept faces a number of problems that complicate the achievement of long-term goals of sustainable development, the main of which are:

1. Lack of integrated approaches to modelling: existing economic models often do not take into account the complexity of the interaction between economic, social and environmental factors. This makes it difficult to predict the consequences of economic decisions in the long term.
2. Data shortage and information quality: to create accurate models, relevant, reliable and large-scale data are necessary. In many countries, in particular in Ukraine, the lack of complete and high-quality statistical information limits the possibilities of modelling sustainable development.
3. Rapid global changes: climate change, economic instability and geopolitical crises complicate forecasting. Traditional methods of analysis are often not adapted to conditions of high uncertainty.
4. Lack of clear methodologies: in many cases, there is a gap between scientific approaches to modelling sustainable development and their practical use in public policy. This leads to the ineffectiveness of economic and environmental programs.
5. Insufficient level of innovative activity: the use of modern modelling technologies — such as artificial intelligence, machine learning, and big data analytics — remains insufficient, which constrains the development of adaptive and predictive economic models.

Sustainable development of the national economy is based on a harmonious combination of three key components: economic, social and environmental. They are interconnected and ensure balanced development of the state in the long term, especially through the progress of human capital, which plays a crucial role in the effective realization of sustainable development.

The economic component is aimed at ensuring stable economic growth, competitiveness of the national economy and efficient use of resources, as well as increasing the well-being of the population through economic sustainability and investment in the future. The development of human capital plays an important role in this process since highly qualified personnel and innovative technologies contribute to increasing productivity and economic efficiency. This includes: sup-

porting macroeconomic stability (stable inflation, budget deficit and public debt); effective management of natural, financial and human resources, which includes the development of professional skills and intellectual potential of the nation; the economy's innovative growth driven by the adoption of advanced technologies; stimulating small and medium-sized businesses as the basis of the economic system; reducing dependence on imports through the development of domestic production, in particular, through improving the skills of labour resources.

The social dimension focuses on securing a high quality of life for the population, social justice and stability in society, which is impossible without the active development of human capital. Human capital determines the level of access to education, healthcare and social services, as well as opportunities for citizens to self-realize. Social investments in education and health are the basis for the growth of the nation's potential. Important aspects are: providing equitable access to social services, healthcare and education; reducing poverty and unemployment by improving the skills of workers and creating new jobs; supporting human rights, including the right to decent work, which contributes to increasing social mobility and economic well-being; overcoming social inequality and discrimination through an inclusive approach to education and employment; developing human capital through investments in knowledge, skills and health, which ensure decent conditions for a full life for every person.

The environmental component is aimed at preserving natural resources and ensuring ecological balance for current and future generations. Human capital is important for solving environmental problems, since awareness and professionalism in the field of ecology stimulate the advancement of environmentally friendly technologies and innovations, contribute to the preservation of biodiversity and ensure sustainable use of natural resources. The main areas include: rational use of natural resources through the introduction of environmentally friendly technologies and energy efficiency; reducing greenhouse gas emissions and preventing climate change through education and the development of environmental awareness among the population; transition to renewable energy sources; ensuring effective waste management (reduction, recycling, disposal); protecting biodiversity and restoring ecosystems, which requires highly qualified personnel in the field of ecology and sustainable development; introducing "green" technologies into production processes, which is possible only through the development of scientific and technical potential and human capital in this area.

These three components are interdependent. Economic development provides resources for the implementation of social programs and environmental initiatives. In turn, social stability contributes to productivity growth, and environmental sustainability guarantees the long-term availability of natural resources for the economy and society.

To achieve effective and accurate modelling and forecasting of the national economy's sustainable development, it is advisable to identify the basic factors for ensuring such development. In the aspect of this study, we consider it advisable to focus on the following indicators of economic, social and ecological advancement of the national economy in relation to the growth of human capital (table 1).

Table 1. Key indicators used for constructing an econometric model assessing the influence of sustainable development components of the national economy on GDP. (Source: generated using data obtained from the website <https://index.minfin.com.ua/ua/economy/gdp/>, https://www.ukrstat.gov.ua/operativ/menu/menu_u/ns.htm, <https://index.minfin.com.ua/ua/labour/unemploy/>, <https://index.minfin.com.ua/ua/labour/salary/min/>, <https://index.minfin.com.ua/ua/economy/index/inflation/>, <https://index.minfin.com.ua/ua/finance/budget/gov/>, <https://www.ukrstat.gov.ua/>).

Year	Real GDP, UAH billion in prices of the previous year	Consumer price index, %	The size of the state budget deficit, UAH million	Expenses on innovations of industrial enterprises, UAH million	Unemployment rate, %	Minimum wage, UAH at the end of the year	Capital investments for environmental protection, UAH billion	Share of energy supply from renewable sources, %	Energy consumption derived from wind and solar power, measured in thousand tons of oil equivalent
	Y	X1	X2	X3	X4	X5	X6	X7	X8
2014	1365.123	124.9	78052.8	7695.9	9.7	1218	7.959	2.6	134.0
2015	1430.290	143.3	45167.5	13813.7	9.5	1378	7.676	3.0	134.0
2016	2034.430	112.4	70130.2	23229.5	9.7	1600	13.390	3.8	124.0
2017	2445.587	113.7	47849.6	9117.5	9.9	3200	11.026	4.4	149.0
2018	3083.409	109.8	59247.9	12180.1	9.1	3723	10.074	4.6	197.0
2019	3675.728	104.1	78049.5	14220.9	8.6	4173	16.256	4.9	426.0
2020	3818.456	105.0	217096.1	14406.9	9.9	5000	13.239	6.6	794.0
2021	4363.582	110.0	197937.4	10171.7	10.3	6500	14.114	6.1	823.0
2022	3865.780	126.6	914701.7	7640.5	21.1	6700	6.446	6.3	800.0
2023	5518.062	105.1	1333110.7	6989.2	18.3	6700	8.284	7.4	847.0

Using the Data Analysis package toolkit and the Regression function in particular, we will construct multifactorial equations for each of the selected components of sustainable development.

Economic component:

$$Y = 10055,39 - 61,1 \cdot X_1 + 0,01 \cdot X_2 - 0,03 \cdot X_3 \quad (1)$$

Social component:

$$Y = 1055,0 - 34,48 \cdot X_4 + 0,62 \cdot X_5 \quad (2)$$

Environmental component:

$$Y = 26,32 \cdot X_6 + 794,65 \cdot X_7 + 0,024 \cdot X_8 \quad (3)$$

The outcomes of the multivariate regression analysis are presented in Table 2.

Table 2. Outcomes of the multivariate regression analysis.			
Components of sustainable development	R	R2	F calculated
Economic	0.906294	0.82136	9.19625
Social	0.945859	0.89465	29.7225
Environmental	0.960612	0.92277	23.8986

Commenting on the results of regression analysis, we can note that all coefficients are within confidence intervals and guarantee the reliability of the model and a high level of correlation between the indicators. Among the components, it is worth noting that the greatest impact on the economic component is the consumer price index with a negative sign and the size of the budget deficit with a positive value, on the social - the unemployment rate with a negative value and the minimum wage, environmental - the percentage of energy sourced from renewables. In order to conduct an in-depth analysis, we will build trend lines in the two-factor analysis of independent variables and real GDP (Figure 1).

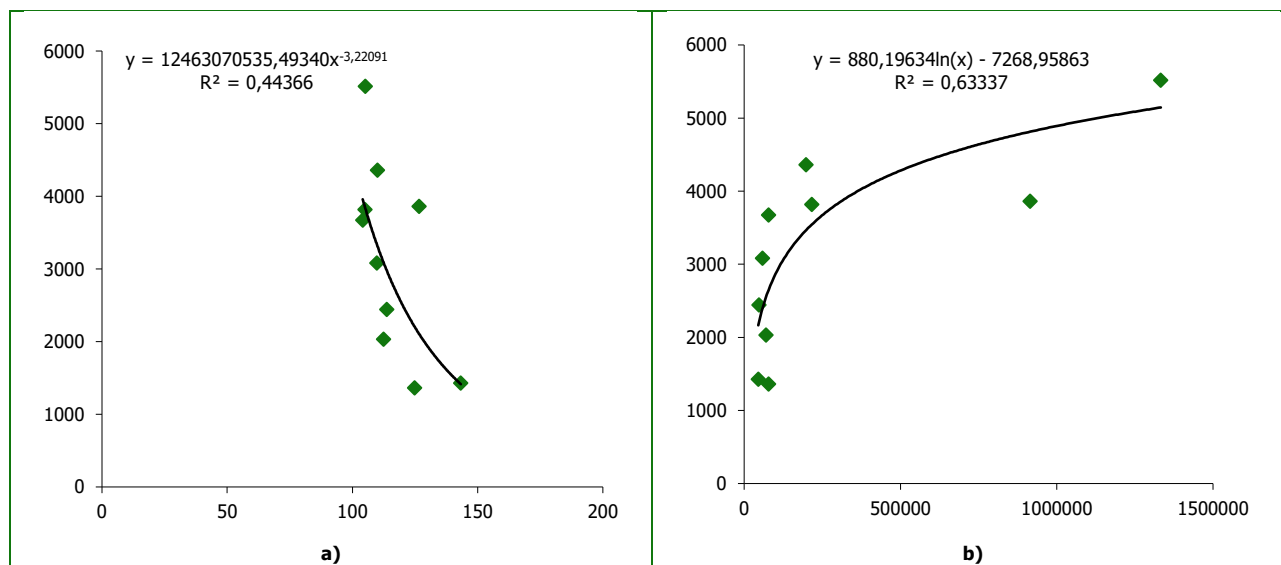


Figure 1. Trend lines of real GDP dependence on: a) consumer price index; b) size of the state budget deficit, UAH million.

The calculated correlation coefficient confirmed the general trend in the multi-factor equation: for the consumer price index it is -0.6, which indicates a strong inverse relationship between the analysed factors, and for the deficit size 0.47 - this indicates a moderate positive correlation between the variables: when one variable increases, the other also tends to grow, but not perfectly. Regarding the factor «Costs of innovation of industrial enterprises, UAH million», the calculations determined the low values of the correlation coefficients (-0.17) and determination (0.131), that is, the relationship between GDP and the specified parameter is absent.

For these social factors, the correlation coefficients are 0.37369 and 0.93717 respectively, so we can trace the direct and strong influence of the minimum wage on GDP, which is described by the power function (Figure 2).

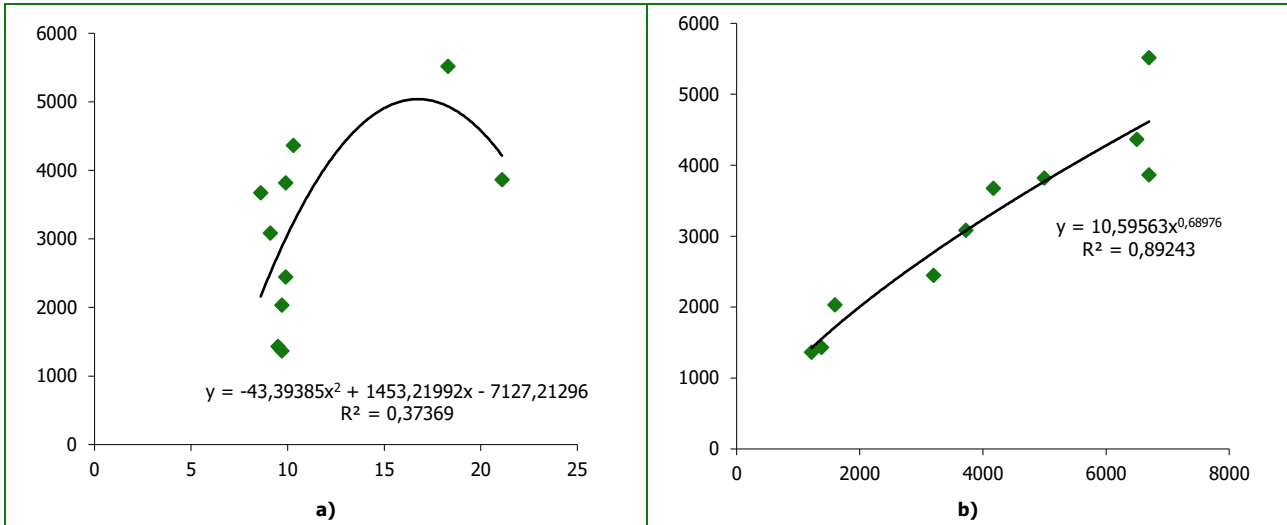


Figure 2. Trend lines of GDP dependence on social factors: a) unemployment rate; b) minimum wage.

The correlation coefficients calculated for these environmental factors are 0.94488 and 0.82413, which indicates a very strong positive relationship between the two variables, so the presented trend lines in the form of a power and logarithmic function are reasonable and can be used for further prediction (Figure 3).

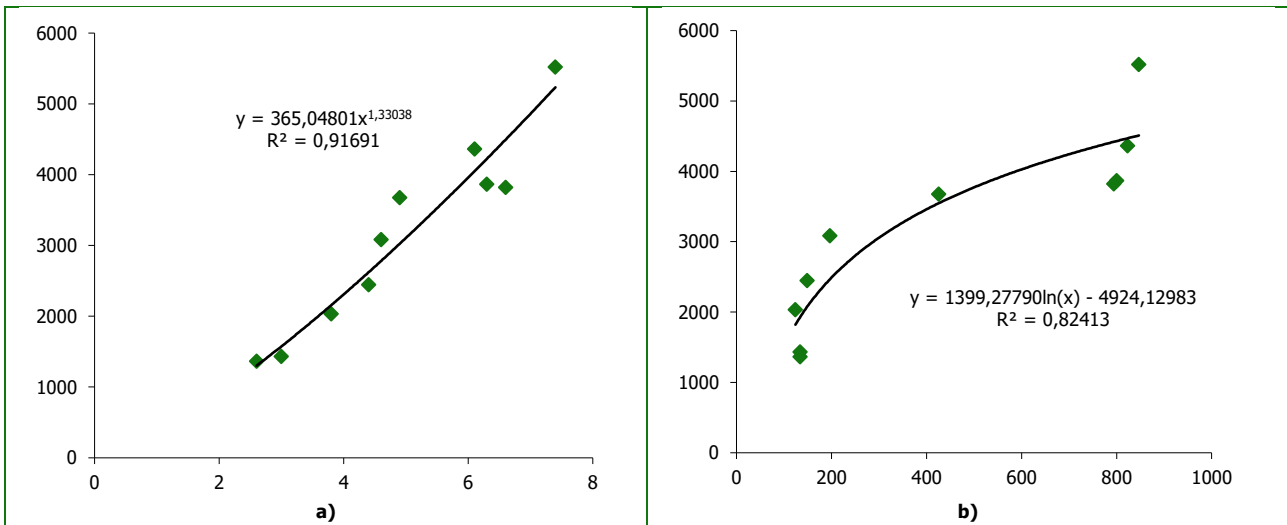


Figure 3. Trend lines showing the relationship between GDP and environmental factors: a) the share of energy supplies from renewable sources; b) energy consumption derived from wind and solar power.

By the method of extrapolation, we established the forecast values of independent variables and substituting them into the equation we calculated the forecast values of GDP in subsequent years according to various impact factors (Table 3).

Table 3. Calculated GDP forecast values for various impact factors, UAH billions.

Year	Consumer price index, %	State budget deficit, UAH million	Minimum wage, UAH	Share of energy supply from renewable sources, %	Energy consumption derived from wind and solar power, measured in thousand tons of oil equivalent
2025	4090.23	4921.52	5562.57	5989.61	5039.07
2026	4317.08	5012.29	5882.79	6467.90	5181.01
2027	4556.51	5094.57	6195.34	6955.15	5309.86
2028	4809.22	5169.81	6500.96	7451.04	5427.85
2029	5075.94	5239.12	6800.24	7955.26	5536.66

Commenting on Table 3, we can state close estimated forecast values of real GDP by various equations and factors, which once again proves the correctness of the built dependencies and trend lines. In the context of ensuring sustainable economic development, it is worth emphasizing the outlined indicators that represent the economic, social and environmental components. The corresponding increase in the allocated parameters will give an increase in gross domestic product in the future.

Based on the research findings mentioned above, it is recommended to highlight the following areas for the development of the national economy in the context of ensuring sustainable development and progress of human capital of an economic, environmental and social nature:

Economic direction:

1. Investment in human capital: the development of the national economy is impossible without active investments in education, professional training, research and innovation. This includes both increasing the level of education and creating conditions for the development of scientific research that stimulates technological progress and the competitiveness of the national economy.
2. Support for small and medium-sized enterprises: fostering entrepreneurship by providing access to credit, tax incentives, and other benefits. This helps create new jobs and enhances the efficiency of labour resource utilization.
3. Innovative development and technological transformation: the implementation of cutting-edge technologies, the internet of things, green energy and others, to increase production efficiency, reduce costs and increase the added value of national products.

Environmental direction:

1. Transition to a «green» economy: development of the economy with an emphasis on the conservation of natural resources, decreasing greenhouse gas emissions, improving energy efficiency, and increasing the use of renewable energy sources. Creation of favourable conditions for investment in environmentally friendly technologies and renewable energy sources.
2. Rational use of natural resources: introduction of technologies that allow reducing the consumption of natural resources and maximizing their efficient use. This involves the creation and application of methods for preserving water, land, and forest resources.
3. Ecological restoration and conservation of biodiversity: the significance of ecosystem restoration and biodiversity preservation for the long-term nation's progress, particularly through the establishment of nature reserves, promotion of ecotourism, and support for sustainable agriculture.

Social direction:

1. Development of education and advanced training of the workforce: implementation of programs that promote access to quality education at all levels, including vocational education aligned with the demands of the contemporary labour market. An important component is the development of scientific research that contributes to the creation of innovative solutions for the economy and society.
2. Improvement of the health care system: creation of conditions for access to quality medical care for all segments of the population. This includes the modernization of medical institutions, access to the latest methods of treatment and prevention, development of healthy lifestyle programs.
3. Social integration and inclusive development: ensuring equal opportunities for all citizens, including low-income groups, women, people with disabilities, and representatives of national minorities. This includes the development of social programs aimed at supporting socially vulnerable groups of the population, as well as creating conditions for their professional realization and social integration.
4. Ensuring social justice: policies aimed at reducing income inequality and ensuring access to basic social benefits for all citizens. This includes the creation of progressive tax systems, as well as measures that reduce poverty, unemployment and social exclusion.

Ensuring sustainable development of the national economy requires an integrated approach that combines economic, environmental and social factors. The progress of human capital is the basis for stable and sustainable development of the country since highly qualified personnel and innovative technologies are the basis for economic growth, environmental

safety and social well-being. Therefore, the integration of these areas is the key to achieving sustainable development in the long term.

DISCUSSION

The results of critical rethinking of Budnikevich I. et al. (2021), Lutak O. et al. (2021; 2023), Stoliyarchuk Ya. et al. (2022), Fadeeva I. et al. (2023), and Nazish Kanval (2024), their scientific discussion and monitoring, give reason to note that the sustainable development of the national economy in the context of human capital progress is gaining increasing weight in modern scientific discourse. The analysis of modern research shows that the factors of economic growth are not only financial and material resources but above all the effective use of human capital. This approach corresponds to global trends, according to which investment in education, health care, and vocational training significantly affects the country's productivity, innovation potential, and competitiveness. However, there is chronic underfunding in Ukraine in Ukraine, which creates significant barriers to sustainable economic growth. The lack of systematic policy in the fields of education, health care and maintenance of innovation limits the ability of the economy to adapt and modernize. This, in turn, has a negative impact on its productivity and weakens its position internationally. Indicators of such a problem are limited access to quality educational and medical services, as well as poor support of innovative technologies and entrepreneurship. This not only limits economic potential but also increases social tensions - in particular due to the increase in poverty, unemployment and social inequality.

Solving these problems requires the formation of a holistic national strategy for human capital development. Such a strategy should cover significant investments in education, professional training, and health care and create conditions for innovation development. At the same time, state support for politicians aimed at attracting both internal and external resources in the development of human resources is important.

Continuing research on the article, we identified the directions of development of the national economy regarding ensuring the sustainable development and progress of human capital in economic, environmental and social direction.

CONCLUSIONS

In the development of theoretical and methodological bases and practical recommendations for modelling and forecasting of sustainable development of the national economy in order to ensure a harmonious balance between economic growth, social justice and environmental stability, the need to integrate human capital progress in the model of sustainable development of the national economy, which ensures a cognitive approach to the economic economy, which ensures a cognitive approach: theoretical and methodological foundations for modelling sustainable development have been developed, which allow to predict the relationship between different components of economic, social and environmental policy, which contributes to the achievement of harmonious development; practical recommendations that follow from the study, provide tools for optimizing investments in human capital and other components of sustainable development, contributing to improving the efficiency of the national economy and improving the quality of life of the population.

The study identified that the key problem within the concept of sustainable development of the national economy is the insufficient integration of human capital progress into strategic development models. The analysis showed that chronic underfunding of education, healthcare and innovation significantly hinders the formation of sustainable economic, social and environmental links necessary to ensure sustainable growth.

The study of the interrelationships between the economic, social and environmental components of sustainable development in the context of the evolution of human capital revealed a close relationship between the level of human capital development and the state's ability to integrate sustainable development goals into national policy. The progress of human capital strengthens the economy's ability to adapt to external challenges, stimulates innovation and ensures high-quality economic growth.

As part of the study, an econometric model was developed that allows assessing the impact of the main components of sustainable development on GDP as a key macroeconomic indicator of the effectiveness of economic activity. The results obtained confirm the significant positive impact of human capital on the country's real GDP. The results of regression and correlation analysis demonstrated the reliability of the econometric model and also revealed the most significant factors influencing the economic, social and environmental components of sustainable development. The consumer price index has the greatest negative impact on GDP, while the budget deficit, minimum wage and the share of renewable energy

demonstrate a strong positive correlation with economic growth. The obtained coefficients and constructed trend lines confirm the feasibility of using the model to forecast macroeconomic dynamics.

Forecast calculations of GDP taking into account the dynamics of human capital development demonstrated a significant potential for economic growth. This confirms the effectiveness of including human capital in sustainable development models as one of the key factors in increasing labour productivity, technological progress and rational use of resources.

Strategic directions of national economic development in the context of ensuring sustainable development should provide for active investment in human capital in combination with environmental responsibility and the social orientation of state policy. This approach will allow for the formation of a balanced model of long-term growth, in which economic efficiency is harmoniously combined with social justice and environmental sustainability.

Therefore, in order to achieve the sustainable development of the national economy, it is necessary to actively invest in human capital, ensuring its effective use through educational programs, vocational training and health care. At the same time, government strategies should help to create an attractive investment environment that will attract both internal and external investments in these key areas. Only with an integrated approach to human capital development and efficient use of economic resources can a stable and balanced development of the national economy in the long run be achieved.

The prospects for further scientific exploration in this area are related to the in-depth study of the relationship between human capital and the parameters of macroeconomic stability, as well as the development of tools for assessing the efficiency of state policy in the field of sustainable development. Research aimed at adapting innovative approaches to measuring the quality of human capital using modern digital technologies, artificial intelligence and large data is of particular relevance. It is also advisable for interdisciplinary analysis that will evaluate the long-term effects of investment in education, health care and science in the context of environmental and social challenges. In future research, attention should be paid to regional features of human capital development in Ukraine, including the influence of demographic changes, migration and post-war reconstruction, which will allow to form a complex model of sustainable development, taking into account the realities of national socio-economic space.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All Authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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МОДЕЛЮВАННЯ РОЗВИТКУ НАЦІОНАЛЬНОЇ ЕКОНОМІКИ В КОНТЕКСТІ ЗАБЕЗПЕЧЕННЯ СТАЛОГО РОЗВИТКУ ТА ПРОГРЕСУ ЛЮДСЬКОГО КАПІТАЛУ

Сталий розвиток національної економіки є ключовою концепцією сучасного державного управління, яка спрямована на забезпечення балансу між економічним зростанням, соціальною стабільністю та збереженням природного середовища. Метою дослідження є розробка теоретико-методологічних основ і практичних рекомендацій щодо моделювання та прогнозування сталого розвитку національної економіки, які забезпечують гармонійний баланс між економічним зростанням, соціальною справедливістю та екологічною стійкістю з особливою увагою до прогресу людського капіталу як ключового фактора, що сприяє підвищенню ефективності всіх складових сталого розвитку. У статті виокремлено проблемні аспекти концепції сталого розвитку національної економіки в контексті прогресу людського капіталу: недостатність інтегрованих підходів до моделювання; дефіцит даних і якість інформації; швидкі глобальні зміни; відсутність чітких методологій; недостатній рівень інноваційної активності. Сталий розвиток національної економіки базується на гармонійному поєднанні трьох ключових складових: економічної, соціальної та екологічної. Побудовано економетричну модель впливу складових сталого розвитку на ВВП як основний макроекономічний показник результативності національної економіки, враховуючи роль людського капіталу як ключового фактора, що впливає на продуктивність праці, інноваційний потенціал та ефективність використання ресурсів, а також із метою проведення поглибленого аналізу; побудовано лінії тренду у двофакторному аналізі незалежних змінних і реального ВВП. Доведено, що найбільший вплив на результуючий показник мають такі незалежні змінні фактори як «Індекс споживчих цін, %», «Розмір дефіциту держбюджету, млн грн», «Мінімальна заробітна плата, грн», «Частка постачання енергії від відновлюваних джерел, %», «Енергоспоживання на основі енергії вітру та сонця, тис. тонн нафти еквівалент». Побудовано лінії тренду окреслених параметрів і залежної змінної, розраховано коефіцієнти

кореляції та детермінації. Здійснено прогнозування розміру ВВП на основі логарифмічних, експоненціальних і степеневих рівнянь залежності. Окреслено напрями розвитку національної економіки стосовно забезпечення сталого розвитку та прогресу людського капіталу економічного, екологічного та соціального спрямування. Методологічною основою дослідження є системний і комплексний підходи. Основні наукові результати дослідження отримано шляхом використання методів: комплексний аналіз, аналіз факторів впливу, стратегічне планування, інтердисциплінарний підхід, системний аналіз і побудова економетричних моделей через використання інструментарію пакета Data Analysis та функції Regression.

Ключові слова: сталий розвиток, економіко-математичне моделювання, економічне зростання, складові сталого розвитку національної економіки, людський капітал

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