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Scientific and methodological approach to assessing and forecasting sustainable energy development of Ukraine

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SUMMARY

Transformational processes occurring in the energy sector, along with the geopolitical conditions of the energy transition, growing energy demand, fossil fuel depletion, and changes in the availability of energy resources, are reshaping the context of research on sustainable energy development. This study systematizes the evolution of the concept of sustainable energy development and examines scientific and practical approaches to assessing Sustainable Development Goal 7 (SDG 7), which focuses on ensuring access to affordable, reliable, sustainable, and modern energy sources.

A scientific and practical approach to assessing SDG 7 is proposed, incorporating an integrated assessment of its dynamics from 2015 to 2023 and forecasting changes in ensuring sustainable energy development in Ukraine. The results account for the impact of extreme conditions on the energy system, which significantly increase the vulnerability of the socio-economic situation due to risks and threats to Ukraine's energy security.

The findings can be used to provide informational support for the development of national and regional energy strategies and the creation of a systemically integrated adaptation mechanism for authorities, businesses, territorial communities, local communities, and households in the context of large-scale transformations in Ukraine's energy sector.

Introduction

Significant changes in the conditions ensuring Ukraine's energy security and independence under extreme circumstances, including military events, necessitate analysis and forecasting of sustainable energy development. They also require the implementation of national goals defined by legislation to enhance the resilience of the energy sector and ensure access to affordable, reliable, sustainable, and modern energy sources. This aligns with the priorities of post-war reconstruction in Ukraine's economic, social, environmental, infrastructural, scientific and technological spheres.

The established indicators of Ukraine's sustainable energy development serve as an analytical tool for assessing national energy production and consumption models. Experts argue that the procedures for developing and applying analytical approaches should consider the country's specific conditions, national energy priorities, and the criteria and goals of sustainable development (Kharazishvili, 2021). Furthermore, the practical implementation of these approaches depends on the availability of statistical resources, expertise, and relevant energy data for decision-making (Gunnarsdottir et al., 2021; Horoshkova et al., 2021).

Assessing sustainable energy development indicators dynamically allows for evaluating progress in implementing energy strategies and identifying areas that require targeted measures and policy interventions.

Method

This study is based on the concept of sustainable energy development, which has evolved and been refined over decades. Analyzing various scientific and methodological approaches, along with analytical tools for multi-criteria decision analysis in identifying promising directions for sustainable energy development, reveals significant diversity and differentiation (Gunnarsdottir et al., 2021; Komelina O., Komelina A., 2022). Choosing an appropriate methodological toolkit is crucial for policymakers, allowing them to assess and develop programs and strategies while effectively monitoring progress toward a more sustainable future at the national level.

Results

To examine the evolving conditions for sustainable energy development in Ukraine, this study focuses on Ukraine's national commitment to Sustainable Development Goal 7 (SDG 7), which aims to ensure universal access to affordable, reliable, sustainable, and modern energy (Onyshchenko et al., 2022; Moslehi et al., 2018). The analysis includes the following indicators: x_1 - Electricity production (billion kWh); x_2 - Technological losses of electricity in distribution networks (%); x_3 - Heat losses in heating networks (%); x_4 - Maximum share of coal imports from a single country or company in total imports (%); x_5 - Maximum share of oil imports from a single country or company in total imports (%); x_6 - Maximum share of natural gas imports from a single country or company in total imports (%); x_7 - Market share of the largest nuclear fuel supplier (%); x_8 - Share of energy generated from renewable sources in total final energy consumption (%); x_9 - Energy intensity of GDP (kg of oil equivalent per unit of GDP, based on 2011 PPP international dollars).

These indicators reflect progress toward achieving accessible and clean energy. Indicators x_1, x_2, and x_3 represent efforts to ensure a reliable and sustainable energy supply through innovative technologies. Indicators x_3, x_4, x_5, and x_6 characterize the diversification of primary energy resource supply. Indicator x_7 represents the share of renewable energy sources in the energy mix, while x_8 measures the economy's energy efficiency. Indicators x_1 and x_8 function as stimulators, meaning their growth enhances energy accessibility and cleanliness. Conversely, indicators x_2, x_3, x_4, x_5, x_6, and x_7 act as destimulators, where their reduction signifies progress toward accessible and clean energy. Each indicator x_i has a target value for 2020, denoted as x^o_i, which corresponds to the national targets set by the SDG 7 countries. This study examines data from the retrospective period 2015–2023. The

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value of x_i in year t of this period is denoted as $x_i(t)$. Each indicator x_i is associated with a set $X_i = \{x_i(t)\}_{t=1}^{T} \cup \{x_i^0\}$, where T represents the duration of the retrospective period ($T = 9$ years). The maximum and minimum elements of this set are denoted as X_i through x_i^{max} and x_i^{min}, respectively. To comprehensively assess progress toward SDG7 targets, the indicators x_i were normalized for comparability. The research methodology is based on the approach developed by Komelina O. and Komelina A. (2022). The comprehensive integral assessment W of SDG7 target achievement is determined as a linear combination of the normalized indicators y_i. To determine the weighting coefficients a_i, we applied the modified principal component method. The coefficients a_i for the comprehensive integral assessment were selected as the squared components of the given vector. This approach allowed for the following assessment to be derived:

$$W=0{,}2044y_1+0{,}2374y_2+0{,}0631y_3+0{,}0833y_4+0{,}0014y_5+0{,}0003y_6+0{,}0551y_7+0{,}1814y_8+0{,}1737y_9$$

The obtained maximum eigenvalue accounts for 64.2% of the total sum of eigenvalues, indicating that the derived comprehensive integral assessment of SDG7 aligns with assessments based on individual indicators. The values of the comprehensive integral assessment throughout the retrospective period are presented in Figure 1.
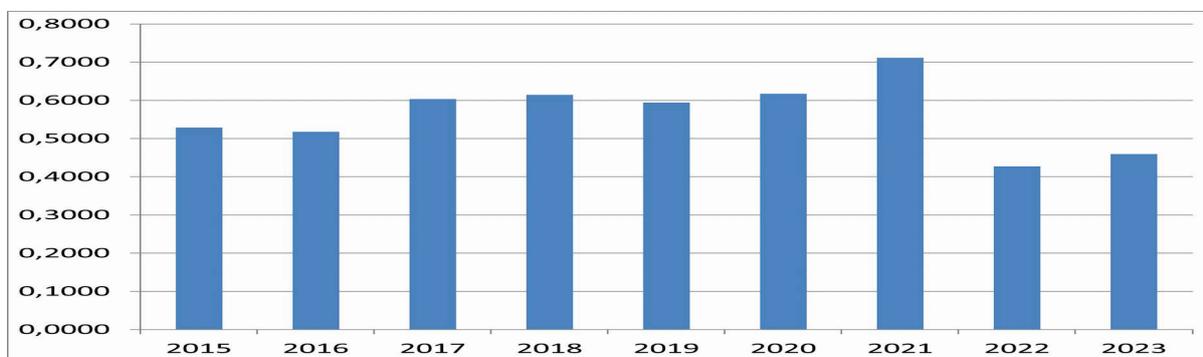

Figure 1 *Dynamics of the comprehensive integral assessment of SDG 7 achievement levels.*

During 2015–2021, there was a general upward trend in this assessment, except for 2016 and 2019, when it experienced a slight decline. In 2022, the assessment dropped significantly due to the aggression by the Russian Federation. However, in 2023, it showed a slight increase, although it remained considerably lower than in 2021. Figure 2 illustrates the growth rates of the indicators for achieving SDG7 during the study period. To forecast the dynamics of the comprehensive integral assessment, we employed adaptive forecasting models: the exponential smoothing model, Holt model, and Brown model. These models assign greater weight to more recent values, making them particularly suitable for unstable conditions. The forecasting results are presented in Table 1, with the Brown model yielding the most optimistic forecast. The forecasting results are represented as triangular fuzzy numbers (Figure 2). The calculations allowed us to determine the forecasted value of the comprehensive integral assessment using the exponential smoothing model based on the Brown model. These results can be used to substantiate the decomposition of sustainable energy development goals, considering energy system losses, and to design an integrated hybrid energy system based on existing international experience (Dongran et al., 2022).
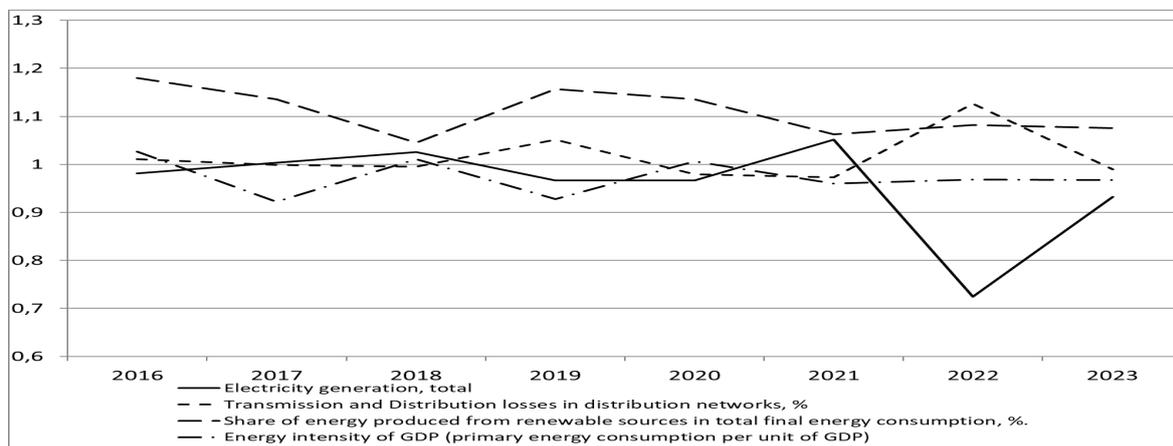
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Figure 2 *Growth rates of the indicators for achieving SDG7, 2015–2023.*

Table 1 *Forecasted values of the comprehensive integral assessment for achieving accessible and clean energy.*

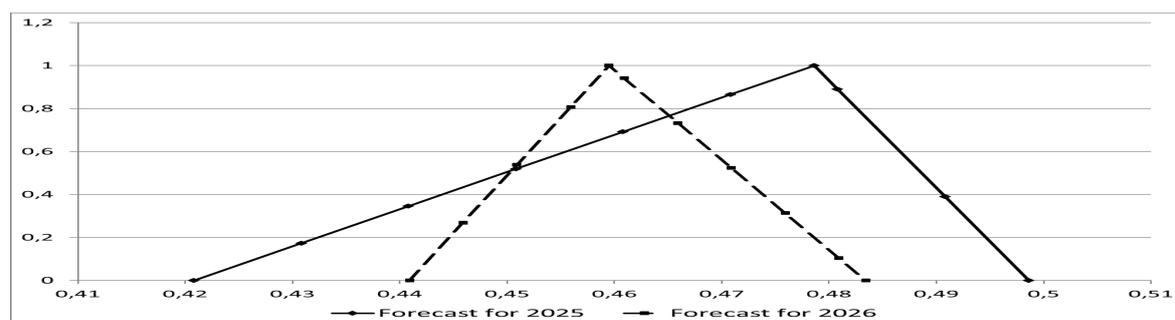| Year	Forecasting model		
	Exponential	the Holt model	the Brown model
2025	0,4208	0,4748	0,4986
2026	0,4409	0,4595	0,4834

Figure 3 *Fuzzy forecasts of the comprehensive integral assessment for achieving SDG7.*

The forecasting results are presented as triangular fuzzy numbers (Figure 2). These calculations enabled us to determine the forecasted value of the comprehensive integral assessment using the exponential smoothing model based on the Brown model.

Conclusions

The proposed scientific and practical approach to assessing the achievement of sustainable energy development goals facilitates the examination of the dynamics of access to affordable, reliable, sustainable, and modern energy sources for all, using SDG7 as an example. It enables the identification of existing trends and forecasting the values of relevant indicators. The absence of a unified framework for evaluating energy-related sustainable development goals broadens the research directions for national and regional energy strategies, incorporating the perspectives of stakeholders in the transformative changes within the energy sector. This approach helps resolve contradictions between new and existing mechanisms for ensuring the energy transition, which stem from technological unpreparedness for implementing innovative projects and the limited availability of investment resources (Justinas et al., 2021; Sovacool et al., 2020; Komelina, Shcherbinina, 2022; Moslehi et al., 2018). The proposed approach is vital for developing systemically integrated mechanisms that help authorities, businesses, local communities, and households adapt to new conditions in the energy and socio-economic systems of the state.

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