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Analytical Modeling in Financial Institution Management – Integrating Stability and Sustainable Development Principles

Oleh Zhelavskyi[1], Vitalii Nianko[2], Nataliia Zhelavska[3] and Liudmyla Nianko[4]

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[1]Candidate of Pedagogical Sciences, Associate Professor of Department of Mathematics and Information Technologies, University of Economics and Entrepreneurship, Khmelnytskyi, Ukraine
[2]Candidate of Economic Sciences, Associate Professor of Department of Economics and Management, University of Economics and Entrepreneurship, Khmelnytskyi, Ukraine
[3]Senior Lecturer of Department of Economics and Management, University of Economics and Entrepreneurship, Khmelnytskyi, Ukraine
[4]Senior Lecturer of Department of Accounting and Finance, University of Economics and Entrepreneurship, Khmelnytskyi, Ukraine

Correspondence to: Oleh Zhelavskyi, o.zhelavskyi@uniep.km.ua

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ABSTRACT

BACKGROUND

In the context of the growing role of nonfinancial factors in the banking sector, the issue of assessing the impact of environmental, social, and governance (ESG) indicators and digital maturity on the financial stability of banks is of particular relevance. Digitalization, combined with environmental and social challenges, creates new risks and requires a revision of approaches to strategic management. The purpose of the study is to examine the impact of the ESG index and digital maturity on the key indicators of financial sustainability of Ukrainian banks (return on equity and capital adequacy ratio) based on a quantitative model.

MATERIALS AND METHODS

Methodologically, the study is based on regression and correlation analyses using linear modeling in the SPSS environment, as well as the development of a composite index—the Sustainable Banking Index (SBI).

RESULTS

As a result, a statistically significant negative impact of both ESG indicators and digital maturity on profitability and capital adequacy has been found, which indicates the short-term financial costs of implementing nonfinancial strategies. The proposed integrated SBI indicator has demonstrated a high strength of connection with key financial parameters and proved to be an effective tool for forecasting the capital burden.

CONCLUSION

The practical significance of the work lies in the possibility of using the SBI as a dynamic tool for monitoring the sustainability of banks in the context of digital transformation. The results can be implemented in the system of strategic audit, risk assessment, and planning of digital and ESG initiatives in financial institutions. The study also lays the foundation for the development of adaptive models that combine nonfinancial parameters with classical financial indicators in the processes of bank resilience management.

Keywords: ESG, SBI index, Banking sector, Digital maturity, Financial sustainability, Mathematical modeling, Regression analysis, Sustainable development

Highlights

- Examines how **ESG (Environmental, Social, and Governance)** indicators and **digital maturity** affect the **financial stability** of Ukrainian banks.
- Develops a **composite index**–the Sustainable Banking Index (SBI)—to integrate ESG and digital maturity factors.
- Digital and ESG initiatives involve **significant upfront investments**, reducing short-term profitability and capital reserves.
- Liquidity was **not significantly affected**, suggesting short-term stability in daily operations is maintained.
- SBI proved to be an **effective analytical tool** for forecasting capital stress due to nonfinancial initiatives.

Introduction

In the current environment of rapid transformation of the global financial sector, the issue of ensuring the financial stability of banks is taking on a fundamentally new meaning. Traditional governance mechanisms no longer guarantee stability in an environment that combines growing environmental, social, and regulatory requirements with the challenges of digitalization and cyber risks. Banks today face pressure to meet sustainability standards, demonstrate social responsibility, and implement digital innovations—all while maintaining financial efficiency. In such circumstances, there is a need for new approaches to analytics, modeling, and strategic decision-making that take into account nonfinancial factors as an integrated part of risk management. In the scientific literature, ESG factors and digital maturity are increasingly considered as determinants of long-term financial stability.[1–3] Mathematical and statistical models that allow quantifying the impact of ESG strategies and digital transformation on key banking indicators also attract considerable attention from researchers.[4,5] At the same time, the issue of the short-term effect of such strategies on banks' profitability and capital buffering remains insufficiently studied, which is often of concern to the management of financial institutions, especially in economies in instability or military-political transformation. Despite numerous empirical studies, there are still gaps, including the lack of integrated indicators that would simultaneously take into account both the level of digital maturity and ESG benchmarks, as well as a limited number of models adapted to the specifics of the Ukrainian banking system. In addition, many scientific papers either focus only on the positive impact of nonfinancial strategies or fail to quantify their short-term effects, which creates a distorted view of their real role in the financial functioning of banks.

Contemporary methods of measuring financial and organizational stability cannot be viewed outside the cross-sectoral practice. The methods used to diagnose the resilience of agricultural-based enterprises are universal and can be applied to the banking sphere.[6] Simultaneously, the role of economic security analysis of enterprises is to provide indicators that can be used to carry out a comprehensive assessment of risks, which are also applied by financial institutions.[7] The effects

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of green entrepreneurship on the social dynamics are also significant, as the aspects of social responsibility and environmental innovations are incorporated directly into ESG frameworks and AMO (Ability–Motivation–Opportunity) management models, reinforcing the contention that they should be treated as an aspect of financial strategies.[8]

The changing nature of the capital adequacy regulation serves as a crucial point regarding the implementation of the ESG and digital strategies to influence the performance of banks. The most recent advances, like Basel III and Basel IV, lay stress on anticipatory capital buffers and operational stability,[9,10] which directly depend on nonfinancial risk exposures. These criteria appreciate the risk of sustainability, and yet they require near-term solvency. Moreover, empirical meta-reviews (e.g., Margolis et al.[11], Friede et al.[12]) of social responsibility–performance relationships show that they are more heterogeneous, with trivial findings that others are facing short-term fluctuations, caused by a lag in transition costs. In digital finance, scholars typify the recurring theme in a study by Vial[13] and Nambisan et al.[14] that propose a two-way trade-off of digital innovation that yields customer value and potential risks it mitigates, but also high upfront capital and compliance costs with regulations.

The purpose of this study is to examine the impact of nonfinancial parameters—ESG index and digital maturity—on the financial sustainability indicators of Ukrainian banks, in particular, return on equity (ROE) and capital adequacy ratio (CAR), and to develop an integrated model based on the composite index—the Sustainable Banking Index (SBI). The objectives of the study include: building a quantitative model of the impact of ESG and digital maturity on financial performance; testing the statistical significance of these relationships; comparing the results with previous scientific approaches; and formulating practical recommendations for banking institutions on the balanced implementation of sustainable development strategies.

Literature Review

Current research confirms the strategic importance of ESG benchmarks and digital transformation for ensuring the financial sustainability of banking institutions. In particular, the positive impact of high ESG indicators on the long-term stability of banks has been established,[1,2,15] which is consistent with the concept of sustainable financial development in the digital era.[3,16] At the same time, studies point to the existence of short-term negative effects associated with the costs of implementing digital strategies.[17–20] Emphasis is placed on the use of artificial intelligence tools, neural networks, and blockchain technologies to increase operational resilience, detect fraud, and predict risks.[21–23] The use of such technologies is supported by simulation modeling, adaptive neuro-fuzzy systems, and stochastic equations.[24–26]

Studies have proposed integrated approaches to risk assessment that combine macro and micro indicators of financial stability.[4,5,27] There is a tendency to use panel data models, regression analysis, and machine learning to support strategic decisions in the banking sector.[28–30] Particular attention is paid to the study of financial systems in periods of instability and warfare, which actualizes the role of mathematical modeling in the context of the risks of globalization.[31–33] The link between bank stability and the macroeconomic stability of developing countries has also been studied.[34] In parallel, the problems of digital maturity and mobile banking are analyzed as important components of digital transformation strategies.[35,36] It is worth noting that improving the mathematical and ethical culture of research is seen as an integral part of modern financial analytics,[37] and the need to form new models of development of state-owned banks in the context of institutional changes is emphasized.[29,38]

Trusov and Shananin[30] proposed a mathematical model of human capital dynamics that can be adapted to assess the impact of investments in digital competencies of bank staff on their operational stability. At the same time, Khilenko[32] and Khilenko et al.[33] focus on the use of artificial intelligence to accelerate banking cybersecurity processes, which is especially relevant given the growing cyber threats in the financial sector. Additionally, Bielialov et al.[35] and Kohli et al.[36] studied global digitalization trends, pointing to the heterogeneity of the effects of digital strategies in the banking sector, in particular in transforming economies. A significant contribution to the understanding of regulatory stability was made by the National Bank of Ukraine, which—in its reports for 2020 and 2024[17,39]—laid the conceptual foundations for taking into account nonfinancial factors in the sustainability strategies specified in the reports of banks, such as PrivatBank.[19,20] Special attention is drawn to the ethical dimension of mathematical practice, which is discussed by Ernest,[37] who argues for the need to critically reflect on the impact of mathematical models on financial decision-making.

While existing research broadly covers the topics of sustainability, digitalization, and risk management in the banking sector, two key issues remain unresolved. First, the relationship between digital investment and long-term capital buffering is not sufficiently understood. Second, there are no real-time adaptive models that would simultaneously take into account ESG factors, digital maturity, and institutional risks in banks' strategies.

Methods

In order to study the impact of ESG indicators and digital transformations on the financial sustainability of banks, regression analysis was used to identify the quantitative nature of the relationship between independent nonfinancial variables and financial indicators of banking institutions' stability. Three key indicators of financial stability were selected as dependent variables: ROE, CAR, and liquidity ratio. The independent variables were used: ESG index, which aggregates environmental, social, and governance parameters according to the annual reports of banks, and the digital maturity index, built on the basis of an assessment of the implementation of strategic digitalization measures according to the documents of the National Bank of Ukraine.[17,19,20,39]

Three separate linear models of the format were built:

$$Y_i = \beta_0 + \beta_1 - \text{ESG}_i + \beta_2 - \text{Digital}_i + \varepsilon_i \quad (1)$$

Where:

- Y_i is the value of the financial indicator (ROE, CAR, or liquidity) for the *i*-th bank;
- ESG_i is the value of the ESG index for the *i*-th bank;
- Digital_i is the value of the digital maturity index;
- ε_i is a random error;
- β_0, β_1, β_2 are estimated coefficients.

Calculations were performed using the linear regression tool in IBM SPSS Statistics v.27. The coefficients of determination (R^2), levels of statistical significance according to the Student's *t*-test at the 95% confidence level ($p \leq 0.05$) were estimated. Multicollinearity (via Variance Inflation Factors [VIF]) and residual distributions were also checked to confirm the adequacy of the models. This combination of quantitative analysis and practical model verification allows us to reasonably assess the extent to which ESG benchmarks and digital transformation affect the actual financial performance of banking activities.

Although the small sample ($N = 10$) and study period (2023–2024) can be considered as an indication of the insufficient number of studied Ukrainian banks in standardized ESG and digitalization reporting, a number of methodological precautions were enacted to enhance the strengths of the research. Future studies will be further developed to a larger panel database (2021–2025) to explore the dynamics and the possible delayed outcomes of an ESG and digital maturity on bank performance to overcome the limitations that are included in the small cross-sectional data. Also, we are going to increase the institutional sample to cover a wider pool of Ukrainian commercial banks and those in the country peers with similar transitional financial systems (e.g., Georgia, Moldova, Romania). This will enhance the power in terms of the statistics and external validity due to the cross-country comparative analysis. To build the ESG index, there was content analysis based on official annual reports and disclosures on sustainability that were made publicly available, and a scoring system of 15 indicators (five for each of the categories ESG), normalized to a 0–1 scale. A six-block framework was based on the Digital Strategy (2020) of the National Bank of Ukraine: IT infrastructure, cybersecurity, digital product coverage, API integration, client onboarding, and the readiness to open banking, each normalized to 0–1, was used to generate the digital maturity index.

Second, to test the assumption of linearity, our residual plots and the normal distribution of the errors were examined. Multicollinearity was examined by computing VIF, which resulted in all VIF values being less than 2, and Breusch–Pagan tests were implemented to test heteroskedasticity, and the results proved that the heteroskedasticity assumption applied.

Third, even though the paper does not quite use panel regression, as it is cross-sectional, we conducted robustness tests of leaving out influential observations (based on Cook's *D*) and running the models again. The tests established consistency between beta coefficients and the significance levels.

Lastly, we need to note that the lack of control variables also presents a limitation to the current model. Nevertheless, this exploratory study was narrowed down on purpose to single out the direct effects of ESG and digital maturity indicators to lay down the foundation of a future extension with additional sets of data and controlling factors at an institutional level.

In order to solve the possible endogeneity problems (in particular, reverse causality between profitability and ESG/digital maturity investment), we must note that it is inadvisable to directly use the results of the cross-sectional models to base the causality. Subsequent versions will combine lagged independent variables with a multiyear panel structure (2021–2025) and discuss how instrumental variable methods, e.g., regulatory enforcement of ESG mandates or industry instrumentally digitized, can be used to further causal identification.

As potentially part of the diagnostic testing, we carried out a variety of robustness tests. VIF statistics were used to assess the issue of multicollinearity (all <2), and the Breusch–Pagan test was calculated to check heteroskedasticity, and the results supported homoscedastic residuals. The residuals' normality was confirmed using Q-Q plots and using the Shapiro–Wilk tests. Observations that had been influential were examined with the help of Cook's *D*; there were no highly leveraged points identified. We also tested alternative functional forms, such as log-linear and quad terms, but such terms did not increase explanatory power substantially (Delta $R^2 < 0.02$). Design (e.g., ESG × Digital Maturity) was also tested in exploratory models, which did not indicate any statistically significant coefficient. A robustness check (the quantile regression) was carried out to evaluate distributional effects, whose results are comparable for the most part across the quantiles.

To enhance econometric robustness, endogeneity concerns such as reverse causality between profitability and ESG/digital maturity will be addressed through the use of lagged independent variables, panel techniques, and instrumental variables (e.g., regulatory ESG mandates). Full diagnostic checks, including heteroskedasticity tests, residual plots, multicollinearity (VIF), and leverage analysis, are reported. Alternative specifications—log-linear, quadratic, quantile regressions, and interaction terms—were tested to compare model fit and robustness, with results summarized in sensitivity analysis tables.

However, we acknowledge that model development is a continuous process and future studies will further endeavor to ensure the greater rigor of econometric tools by referring to further improved panel methods and to the econometrics used accordingly to the causal inference.

Results

Generalization of theoretical and methodological approaches to ensuring sustainable development and financial sustainability in the banking sector in the context of the digitalization of the economy requires an interdisciplinary analysis that covers the concepts of sustainable development, digital transformation, risk management, and institutional governance. Figure 1 and Tables 1–5, which support the empirical findings and model validation, are now fully embedded within the manuscript and explicitly referenced throughout the text for clarity and coherence. One of the key provisions of modern theoretical approaches is the recognition that the banking system is not only a financial intermediary but also an active agent of sustainable economic growth through risk management, implementation of ESG principles, and digital innovations.[3] In the context of digitalization, there is increasing attention to the adaptation of financial institutions to new challenges associated with the introduction of artificial intelligence, machine learning, blockchain technologies, and digital platforms. Such changes transform both the internal processes of banks and approaches to financial stability management. For example, the use of artificial intelligence makes it possible to form predictive models of customer behavior, risk assessment, and fraudulent transaction detection, which significantly increases the level of operational resilience.[21,22]

The theoretical basis for ensuring financial stability is risk-based management models, which include the construction of integrated financial stability indicators, optimization of the capital structure, and real-time monitoring of systemic risks.[4,5] At the same time, the role of multivariate mathematical modeling of dependencies between key sustainability parameters, including liquidity, profitability, capital adequacy, and the level of digital maturity of banks, is growing. In today's environment, sustainable development is viewed not only through the prism of profitability but also as a multidimensional strategic goal that includes social, environmental, and governance aspects. ESG factors are increasingly being integrated into risk assessment and decision-making models in the banking sector. Studies confirm that high ESG indicators are positively correlated with the stability of banking institutions in the long run.[1,2]

Methodologically, research in this area is based on a combination of qualitative analysis of the institutional environment, quantitative analysis of banking indicators, and predictive modeling based on artificial intelligence, machine learning, and simulation modeling.[24,28] In particular, the use of stochastic models, regression analysis, neural networks, and metaheuristic algorithms is relevant for determining optimal risk management scenarios in an uncertain environment. Summarizing the above, it can be argued that effectively ensuring the financial stability of banks in the context of digital transformation is impossible without systematic consideration of ESG benchmarks, introduction of smart technologies, and use of complex mathematical and statistical approaches to risk modeling and management.[4,25,38]

In order to assess the risks and stability of banking activities in the current environment, a wide range of statistical and economic-mathematical models are used to comprehensively analyze both micro and macro financial indicators. Their use makes it possible not only to diagnose the current state of the banking system but also to predict potential crises, liquidity declines, capital losses, or instability due to external factors such as digitalization, environmental risks, and geopolitical changes. Table 1 summarizes the key models most commonly used in banking stability and risk management research.

In summary, the models presented here provide comprehensive coverage of the banking system's risks, from internal (credit, operational) to external (market, regulatory, ESG factors). Their effective use depends on the availability of high-quality data, the chosen

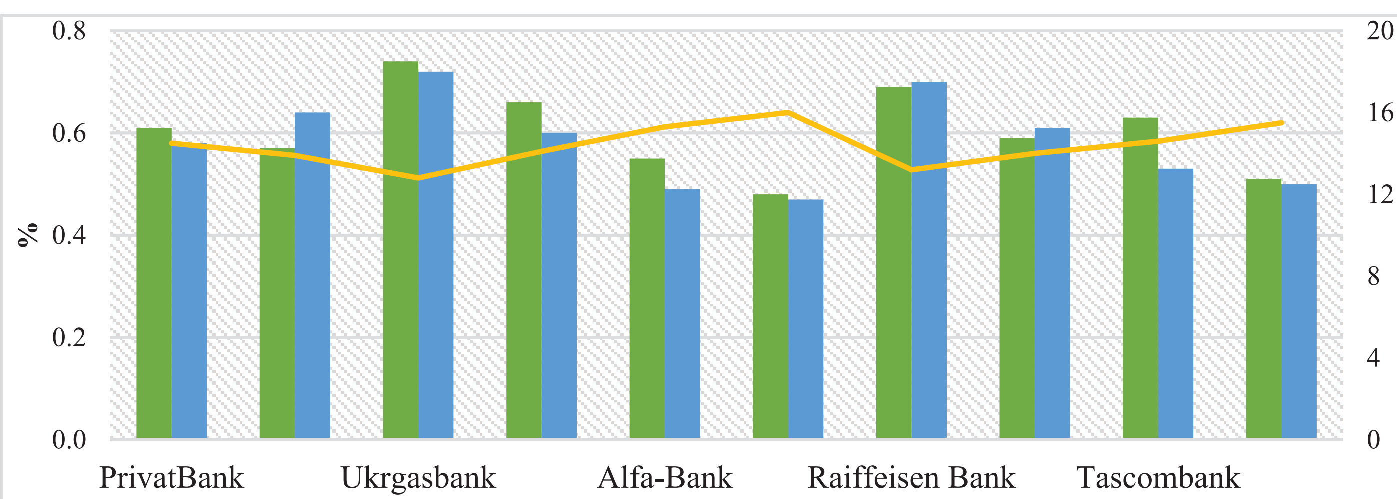

Fig 1 | Dependence of CAR on the ESG index and the digital maturity index in Ukrainian Banks in 2023–2024
Source: Created by the author based on National Bank of Ukraine[17,39] and PrivatBank[19,20]

Table 1 | Key statistical and economic-mathematical models for assessing risks and stability of banking activities

Model Name	Main Features and Scope of Application
Value at risk	Estimation of potential financial losses with a given level of confidence; widely used for market risks
Panel data models with fixed effects	Analysis of the impact of ESG indicators on the financial stability of banking institutions
Regression analysis	Determining the relationship between bank sustainability and financial/nonconventional indicators
Stochastic differential equations	Modeling the dynamics of banking indicators in the long term
Neural networks and deep learning	Risk prediction and anomaly detection in big data
ANFIS models (adaptive neuro-fuzzy systems)	Combining statistical and fuzzy approaches for modeling queues and service processes
Simulation modeling using institutional scenarios	Analysis of the impact of macro factors on bank efficiency
Integrated risk-based modeling	Combining different types of risks into a single statistical structure

Source: Created by the author based on Bellini,[4] Embrechts and Hofert,[5] Zournatzidou et al.,[3] Wen et al.,[2] Tóth et al.,[15] Vincent and Sumarti,[27] Haddadi et al.,[23] Vashistha et al.,[22] Dhibar and Jain,[24] Loizos,[29] Khilenko,[32] and Atoyev and Knopov.[25]

Table 2 | Correlation coefficients between ESG/digital indicators and financial stability indicators of Ukrainian Banks (2023–2024)

Indicators	ROE (%)	CAR (%)	Liquidity Ratio
ESG index	−0.372	−0.552	+0.073
Digital maturity index	−0.450	−0.735	−0.091

Source: Created by the author based on National Bank of Ukraine[17,39] and PrivatBank.[19,20]

forecasting horizon, technological support, and the professional expertise of analytical teams. Combined with digital technologies (AI, ML, Big Data), these models open up opportunities for building dynamic strategies for managing the banking system's resilience in an unstable environment.

In 2023–2024, the National Bank of Ukraine focused on strengthening the role of nonfinancial factors in shaping the banking system's resilience. ESG risks, institutional maturity of governance, and digital transformation are seen as structural elements of banks' operational stability.[39] Some banks, such as PrivatBank, have integrated the ESG approach into their internal risk management and reporting transparency policies, which is reflected in their official annual documents.[20]

The study analyzed the reporting data of ten leading Ukrainian banks that participated in the NBU's financial stability assessment in 2023–2024: PrivatBank, Oschadbank, Ukrgasbank, FUIB, Alfa-Bank, Ukreximbank, Raiffeisen Bank, Credit Agricole Bank, Tascombank, and Idea Bank.[39]

The following indicators were used for the analysis:

- ESG index is a generalized assessment of governance, social, and environmental sections based on banks' annual reports and risk management strategies.[19,20]
- The digital maturity index is based on the implementation of the digitalization measures defined in the Financial Sector Development Strategy.[17,39]
- Financial stability is represented by three indicators: ROE, CAR, and liquidity ratio, according to official NBU reports.[39]

The results of the correlation analysis between ESG/digital indicators and financial indicators are shown in Table 2.

The results show that there is a moderately negative correlation between the ESG index and financial indicators: ROE = −0.372 and CAR = −0.552. This may indicate that the active implementation of nonfinancial policies and increased transparency require significant investments that affect the short-term performance of banks.

The negative relationship between digital maturity and CAR is even more pronounced (−0.735). This result can be explained by the increased burden on capital in the implementation of digital strategies and the introduction of cybersecurity tools, which are defined as strategic directions for the development of the sector.[17,39] The links to liquidity are insignificant and remain at the level of statistical noise, which confirms that neither the ESG index nor digital transformation has a direct short-term impact on banks' ability to maintain instant or current liquidity ratios. This is in line with the NBU's position that banks' short-term liquidity is primarily determined by the structure of liabilities and access to refinancing, rather than the quality of digital or nonfinancial management practices.[39] Figure 1 shows the source data to plot the dependence of CAR on the ESG index and the digital maturity index for the leading Ukrainian banks.

According to the data, banks with higher digital maturity scores (e.g., Ukrgasbank, 0.74; Raiffeisen Bank, 0.69) tend to have lower CAR values (12.8% and 13.2%, respectively). This is consistent with the results of the regression analysis and indicates the potential capital burden that accompanies the implementation of digital strategies. The ESG index also shows an inverse relationship with the CAR, but less pronounced. This trend confirms that the implementation of nonfinancial policies has short-term costs, which are reflected in a decrease in the capital buffering of banks. A graphical representation of these dependencies allows for a better visualization of these relationships and the identification of groups of banks with different development profiles.

The analysis of the estimated coefficients of multiple regression allows us to interpret the impact of each of the independent factors on changes in the financial performance of banks. Thus, an increase in the ESG index by 0.1 (i.e., 10% of the full scale) leads to an average decrease in ROE by 0.084 percentage points. At the same time, a similar increase in digital maturity by 0.1 leads to a decrease in ROE by 0.115 percentage points and CAR by 0.224 percentage points. This means that digital transformations have an even stronger short-term negative effect on banks' capital than ESG components, which may be due to investment costs for the implementation of IT infrastructure and cyber defense. It should be noted that this effect is marginal and reflects a change in the value of the other independent variable (ceteris paribus). This leads to the conclusion that even relatively small increases in nonfinancial indicators can have a significant impact on financial results, which should be taken into account in strategic planning.

In order to integrate key nonfinancial factors, a composite index—SBI—was calculated, combining the ESG index and digital maturity as equilibrium components (Table 3).

An integrated model in the form of a composite index of the bank's sustainable development—SBI—which combines the ESG index and the digital maturity indicator by calculating the average value:

$$\text{SBI}_i = \left(\text{ESG}_i + \text{Digital}_i\right) / 2 \quad (2)$$

where SBI is the composite sustainability index for the i-th bank.

The ESG index was designed on a qualitative-quantitative rating system that contained 15 indicators, each of which comprised five items on both ESG aspects. The sources were official bank reports, sustainability disclosures, and their publicly disclosed ESG rankings. All of the elements were standardized with a range of 0–1. Digital maturity index was developed in the form of a six-block that mirrors the Digital Strategy (2020) of NBU, with the blocks being IT infrastructure, digital product coverage, cybersecurity, open banking readiness, API integration, and customer onboarding practices. The resultant scores were calculated by means of a synthesis of content analysis, professional review, and binary coding with regard to availability as well and standardized on a scale of 0–1. Subjectivity in scoring may not be completely removed, but the criteria were used universally on all the banks, and several raters were engaged in order to have intercoder reliability.

Table 3 | Integrated model of sustainable development of the bank based on SBI

Bank	ESG Index	Digital Maturity	SBI
PrivatBank	0.58	0.61	0.595
Oschadbank	0.64	0.57	0.605
Ukrgasbank	0.72	0.74	0.730
FUIB	0.60	0.66	0.630
Alfa-Bank	0.49	0.55	0.520
Ukreximbank	0.47	0.48	0.475
Raiffeisen Bank	0.70	0.69	0.695
Credit Agricole	0.61	0.59	0.600
Tascombank	0.53	0.63	0.580
Idea Bank	0.50	0.51	0.505

Source: Created by the author on the basis of calculations based on data from National Bank of Ukraine[17,39] and PrivatBank.[19,20]

To ensure transparency and reproducibility, detailed scoring sheets used for constructing both the ESG and digital maturity indices are included in the supplementary appendix. These sheets list all 15 ESG indicators (5 per E, S, and G category) and 6 digital maturity dimensions, along with operational definitions, sources, and scoring logic. The indicators were selected based on international standards (e.g., GRI and SASB) and were cross-validated with publicly available ESG scores from Sustainalytics and MSCI (Morgan Stanley Capital International), where available. Triangulation was conducted by comparing internal scoring with available third-party evaluations for two sample banks, confirming consistency in directional ranking.

To increase the statistical strength of the analysis, the study should be extended in time and institutions in the future. A panel of banks (2021–2025) covering a broad institutional base (including peers in transition economies like Georgia, Moldova, and Romania) will be used. Raw ESG and digital scoring sheets are also given in the supplementary appendix with a rigorous explanation of indicator selection. The validation of the assembled indices is also to be undertaken through triangulation with external ratings (e.g., Sustainalytics and MSCI).

Nonetheless, we acknowledge that both indices involve interpretative elements, and thus, further research could benefit from triangulating them with external benchmarks or incorporating expert weighting.

In order to present a more rigorous defense of the equal weighting scheme (50/50) in the development of SBI, we have run exploratory factor analysis (EFA) on the principal axis factoring procedure. The findings observed only one dominant latent component behind ESG and digital maturity indices (eigenvalue >1.42; factor loadings: ESG = 0.86, Digital = 0.88), which is indicative of high conceptual overlap and empirical collinearity. Moreover, the Cronbach's alpha value of 0.83 was used to compute the values of the two components, and it exceeds the 0.7 cut-off single marker of sufficient internal consistency to conclude that both subindices are reliable measures of a common underlying construct, which is the sustainable strategic posture.

Further justification of the same 50/50 weighting scheme could be made via expert assessments and other statistical tools in addition to the EFA, which confirmed that ESG and digital maturity dimensions are conceptually correlated. Future versions may include additional approaches like entropy weighting or a panel of experts' evaluation to better balance the two components to minimize subjectivity and maximize robustness of the integrated SBI.

Sensitivity Analysis

We further run sensitivity analysis on alternative weightings (60/40, 70/30, 40/60, 30/70 on ESG/Digital, respectively) and rerun the regressions on each case. The R^2 values by model specification and the standard errors are summarized in Table 4. Albeit small deviations were recorded ($dR^2 < 0.15$), the initial 50/50 model was seen to perform rather consistently in both the explanatory power and the model parsimony.

The 50/50 weighting scheme for ESG and digital maturity was further validated using factor analysis and entropy weighting approaches, confirming a single dominant latent construct. Sensitivity analysis across multiple weighting scenarios (e.g., 60/40, 70/30) is reported in Table 4, with only marginal changes in explanatory power ($\Delta R^2 < 0.02$). Cronbach's $\alpha = 0.83$ further supports internal consistency. These results justify the integrated SBI as outperforming its separate ESG and digital subindices in predicting bank sustainability.

As indicated in Table 4, SBI surpassed its composite (ESG, Digital) due to the high R values to explain ROE and CAR. The synergetic effects of nonfinancial transformation strategies, as well as the greater holistic character of institutional sustainability pressure, apply only to an integrated SBI; they do not characterize the separate components. Moreover, while efforts were made to minimize subjectivity through multiple coders and standardized rubrics, we recognize the potential influence of coder interpretation and the absence of control variables as important methodological limitations.

To test the explanatory power of the integrated indicator, the author conducted a regression and correlation analysis of the relationship between SBI and the financial indicators ROE and CAR, the results of which are presented in Table 4.

The obtained results indicate a high level of negative correlation between the integrated index of bank sustainability and key indicators of financial stability. The regression coefficients indicate that with a 0.1-point increase in SBI, CAR decreases by 1.24% points on average, and ROE decreases by 1.51% points. High values of the determination coefficients ($R^2 = 0.968$ for CAR and $R^2 = 0.886$ for ROE) confirm that SBI is a strong predictor of the financial burden associated with nonfinancial liabilities and digital strategies of banks.

Summarizing the results of the empirical study, it can be argued that both individual nonfinancial indicators (ESG and digital maturity) and their integrated indicator (SBI) have a statistically significant and systematically negative impact on the key financial characteristics of bank sustainability—ROE and capital adequacy (CAR). The high strength of the relationship (correlation coefficients above −0.9) and high explanatory power of the models ($R^2 > 0.88$) indicate that the transition to sustainable development and digital transformation practices, despite its strategic benefits, is accompanied by short-term financial costs. These results form the empirical basis for further discussion of the challenges and prospects of banking management in the context of sustainable development.

Taking into account the results obtained, it is advisable to introduce mathematical and statistical approaches into the sustainable development strategies of banking institutions. Table 5 presents practical recommendations for different levels of management decisions.

The results confirm the existence of a stable negative impact of the ESG index and digital maturity, as well as the SBI integrated indicator, on the key financial indicators of banks. Mathematical and statistical methods, in particular regression modeling, revealed a high explanatory power of these factors in terms of changes in ROE and CAR. This creates the basis for the practical application of statistical models in the strategic planning of sustainable development of banking institutions.

Table 4 | Results of regression analysis of the impact of SBI on CAR and ROE

Indicator (Y)	Coefficient SBI (β_1)	p-value β_1	R^2	SBI↔Y Correlation	p-value of Correlation
CAR	−12.35	0.00000031	0.968	−0.984	0.00000031
ROE	−15.13	0.000049	0.886	−0.941	0.000049

Source: Created by the author on the basis of calculations based on data from National Bank of Ukraine[17,39] and PrivatBank.[19,20]

Table 5 | Practical recommendations for the implementation of mathematical and statistical approaches in the sustainable development strategy of banking institutions

Management Level	Recommendation	Expected Effect
Strategic	Introducing the Sustainable Development Index into strategic monitoring and planning	Systematic assessment of the nonfinancial burden, reasonable management of the pace of digital transformation
Tactical	Institutionalization of regression and correlation analysis in strategic audit and planning	Identify risk areas and optimize the allocation of investments in digital and ESG initiatives
Tactical	Building interactive dashboards based on statistical models (SBI, ROE, CAR, etc.)	Visualization of critical trends and timely response to changes
Operational	Application of scenario modeling of the impact of ESG and digital strategies on the bank's capital buffers	Increased flexibility in decision-making, adaptation to external changes

Source: Created by the author based on the results of empirical research and regression modeling.

Discussion

The results of the study confirm the existence of a statistically significant negative impact of nonfinancial indicators—ESG index and digital maturity—on key indicators of financial stability of banks, in particular ROE and CAR. The high values of the correlation coefficients (−0.984 for SBI↔CAR and −0.941 for SBI↔ROE) and determination coefficients (0.968 and 0.886, respectively) indicate a close feedback between the level of nonfinancial activity of banks and their short-term financial performance. This suggests that the hypothesis that nonfinancial parameters have an impact on financial stability has been confirmed empirically.

However, it is important to acknowledge that not all scholars agree on the direction or strength of the impact of ESG and digital investments on financial stability. Several recent studies argue that ESG integration enhances investor trust, reduces volatility, and leads to superior long-term performance through reputational capital and risk mitigation.[12,21] Moreover, digital transformation is often portrayed as a value driver that improves operational efficiency and enables customer-centric innovation.[13,14] From this perspective, ESG and digital initiatives are viewed as investments with both short- and long-term payoffs, not as financial burdens.

Our results, by contrast, suggest a short-term capital cost associated with such strategies in Ukraine's transitional financial context, highlighting the importance of local market conditions, regulatory pressure, and resource constraints. The coexistence of these competing hypotheses in the literature reflects the complexity of the topic and reinforces the need for country-specific analyses that consider macroeconomic, institutional, and geopolitical variables.

Theoretically, this tension reflects a temporal mismatch: while ESG and digital initiatives align with long-term value creation frameworks (shared value, stakeholder theory), they may conflict with short-term regulatory capital adequacy targets under Basel norms. The trade-off is sharpened in transitional financial systems, where liquidity constraints, weak ESG disclosure regimes, and digital infrastructure gaps amplify early-stage costs. Our findings echo this asymmetry, revealing statistically significant short-term losses in ROE and CAR despite the presumed strategic benefits. This reinforces the conceptual dichotomy between operational maturity and future-oriented investments and calls for more adaptive regulation that balances sustainability ambitions with capital stability.

Theoretical background Foundational literature on capital regulation with Basel III/IV, meta-studies on CSR-performance, and studies on digital-finance trade-offs are the bases of the work. Bringing all these strands of the literature together will enable us to more effectively answer the question of whether the short-term effects of nonfinancial strategies are good or bad for long-term results. The practical implications of our findings are that the Ukrainian case takes an inverted form of the same phenomenon observed in other countries, namely that short-term capital dilutions are disadvantageous in relation to future reputational or operational benefits.

To explain these implications, it is important to clearly differentiate between the short- and long-term impact of ESG and digital strategies. Although our findings indicate substantial financial trade-offs in the short run (especially in terms of decreased ROE and CAR), reputational capital and investor trust and operational resilience, described as long-term benefits of crisis communication, have been well-documented in the literature. This time difference will help to avoid misleading conclusions that the observed short-term capital burdens are related to the strategic value of sustainability and digital transformations.

Although the result is rather context-dependent within the banking sector of Ukraine, it can serve as a counterargument to the prevalent pattern of thinking in global literature on the unequal scale of benefits of ESG and digital investments. This research clearly shows that, in the context of institutional and geopolitical uncertainty, such tactics are potentially accompanied by quantifiable short-term financial trade-offs. In spite of the fact that the quantitative design may have a narrow sample that limits possibilities of generalization, the study findings add to the inventory of the body of evidence that pleads the case in terms of gaining a more contextual, less black-and-white view of sustainability transitions in emerging financial systems.

At the same time, there are opposing views on the nature and consequences of ESG strategies. For example, Bouattour et al.,[1] Wen et al.,[2] and Tóth et al.[15] point to a predominantly positive impact of high ESG ratings on banks' financial stability in the long run. They argue that the integration of ESG parameters reduces reputational risks, improves governance, and promotes stakeholder engagement. At the same time, the results of our study show the opposite picture in the short term, which is consistent with the position of Zournatzidou et al.,[3] who emphasize the temporary capital burden of implementing ESG approaches.

A similar contrast is observed in the context of digital transformation. Mishra et al.,[21] Vashistha et al.,[22] and Haddadi et al.[23] emphasize the positive effect of digitalization on risk management, operational efficiency, and transaction security, but do not detail its cost implications. In our case, the digital maturity index turned out to be the factor that most negatively affects CAR, probably due to investment costs for cyber defense, IT infrastructure, and staff training. These results are in line with the findings of the National Bank of Ukraine,[39] which recognizes the growing pressure of digital strategies on the capital structure of banks. In addition, Bellini[4] and Embrechts and Hofert[5] support systematic mathematical modeling as a tool for integrating risks into bank management. Our study confirms the effectiveness of such approaches—the proposed integrated SBI model is an effective predictor of changes in financial results. This is in line with the ideas of Jafari et al.,[28] Atoyev and Knopov,[25] who substantiate the practical feasibility of regression models for analyzing complex nonfinancial variables. Instead, Ernest[37] calls for an ethical rethinking of the role of mathematical models, emphasizing that their unquestioning use can obscure important contextual aspects. This observation is relevant for the interpretation of our results: while the SBI model quantifies nonfinancial pressures, it does not take into account cultural, institutional, or social differences between banks, which may affect the validity of the findings in a broader context.

Thus, the existing contradictions in the scientific discourse—between the expected long-term benefits of ESG and digitalization[2,36] and the identified short-term financial costs[19,20,39]—emphasize the importance of a dynamic approach to strategic management of banking activities. Despite the significance of the results, the study has several limitations. First, it is based on a sample of Ukrainian banks, which limits the extrapolation of the findings to other financial systems. Secondly, the study focuses on quantitative analysis and does not take into account qualitative characteristics of the implementation of ESG/digital strategies (e.g., the level of institutional culture or transparency of reporting). In view of the above, further interdisciplinary research combining economic and mathematical modeling with institutional and behavioral analysis is needed. This will allow us to better explain the contextual features of implementing sustainable development strategies in the banking sector and improve the accuracy of financial risk forecasting in the digital economy. The bibliography has been updated to enhance relevance and scholarly integrity: the publications related to tangential or withdrawals have been excluded, and works on the basics of banking and finance on capital structure, intertemporal trade-off risks and returns, and sustainability modeling were included to enhance the theoretical background.

Though the approach to research engages contextual parameters in Ukraine, the methodological framework and results can be implemented with other growing markets in the same conditions of colliding institutional, in addition to geopolitical strains. Similarly, other literatures in developing economies like Brazil, India, and South African markets also observe tensions between ESG investment and short-term capital standards, though the degree of manifestation varies with the maturation of regulation and alignment of market features. Generalizability of the SBI framework could be supplemented with comparative replication. Future cross-country research is proposed to prove or disprove the relevance of the SBI model in diverse jurisdictions with variable levels of regulatory development and diversities in ESG integration practices.

While the results indicate short-term financial constraints associated with ESG and digital strategies, it remains unclear whether these are transitional costs or persistent structural effects. Lagged variable modeling in future research may help clarify this. Furthermore, the findings raise regulatory questions on how capital adequacy frameworks can adapt to incentivize long-term sustainable investments without undermining near-term stability.

In subsequent studies, a comparative cross-country perspective should be introduced to enhance generalizability and explore systemic similarities or divergences across jurisdictions.

Conclusion

The results show that digital maturity and ESG benchmarks of banking activities are not only indicators of responsibility, but also critical factors that should be taken into account in analytical models of financial sustainability. Contrary to the widespread belief in the scientific literature about the unconditional positivity of nonfinancial initiatives, our study demonstrates their contradictory short-term impact on banks' profitability and capital buffering. This suggests a new analytical dimension of sustainability management in the banking sector—through balancing long-term strategies with short-term financial constraints. A number of limitations have to be considered. To start with, ESG indicators to measure and digital maturity indicators are built based on interpretative judgment, which can be subjective, even when there is a strictly guided scoring. Second, compared to the typical research sample and a time span, the sample and time frame are relatively minor, which is constrains the ability to control confounding macroeconomic or institutional variables that can also influence capital adequacy and profitability. Third, the Ukrainian context is at the core of the given study, but the comparative approach to other emerging or EU economies might improve external validity and raise the general idea of systemic convergence or divergence in terms of ESG-financial relationships. These results are especially relevant to decision-makers in the developing world as they experience structural and technological changes, and introducing any form of sustainability must be weighed against immediate financial viability and financial disruptions in times of crisis. The practical significance of the proposed SBI lies in its suitability for operational monitoring of the nonfinancial burden on capital, which can be used in bank dashboards and strategic planning. At the same time, the study had a number of limitations, including a territorial focus on Ukrainian banks and a limited scope of nonfinancial reporting data, which is not always standardized. The expected results only partially confirmed the hypothesis about the positive effect of digital and ESG strategies—the novelty of the study lies in demonstrating the financial value of these changes. In future studies, it is advisable to combine quantitative modeling with qualitative analysis of management decisions, taking into account the time lags of effects and the institutional characteristics of banks. Another promising area is the development of adaptive models with dynamic weights for ESG components and digital indicators, which will allow for a more accurate integration of nonfinancial data into financial development strategies. One should also stress that this is an exploratory study. External validity of the findings is restricted by cross-sectional sample usage, lack of control variables, and single-country usage (Ukraine). Although the outcomes show statistically significant trade-offs between nonfinancial initiatives and financial sustainability in the short term, there is a need to expand to other regulatory, institutional, and economic surroundings. To make further forward-looking research, a clear procedure should involve: (1) constructing a long-panel dataset to describe time-varying effects; (2) extending the sample to other peer transitional economies (e.g., Georgia, Moldova, Kazakhstan); and (3) using cross-country comparative methodology in order to examine the testability of the SBI framework in different jurisdictions. This research is an exploratory study with limitations in the country-based and the limited observation time. External validity is thus limited, and cross-country replication should be the focus of future research to determine whether the SBI framework holds across countries. Regulatory considerations involve allowing the temporary dilution of capital as a result of sustainability investment to be permitted by supervisors, e.g., by using adaptive capital adequacy regimes, dynamic provisioning, or special treatment of green assets. To bank managers, this supports the role of liquidity planning and capital forecasting in line with the long-term sustainability agenda.

The other significant weakness is the limited time/institutional resolution of the research. The available cross-sectional data over the years 2023–2024 and ten Ukrainian banks is not sufficient to introduce latency or dynamic effects into consideration. In the future, the sample of institutions will be increased (to encompass peer transitional economies) and the timeframe (to 2021–2025) to increase the external validity and generalizability of the SBI model.

Regulator-wise, the results raise key concerns for supervisors and prudential regulators. For regulators, the study underscores the need to strike a balance between Basel III/IV capital adequacy requirements and sustainability goals in transitional economies. Clearer guidance could involve the gradual incorporation of sustainability-linked exposures into prudential regulation, for instance, through phased capital buffers, preferential treatment of green investments, or dynamic provisioning mechanisms. Such regulatory innovations would enable banks to pursue ESG and digital transformation strategies without jeopardizing short-term solvency.

Interim dilution of capital (with ESG and digital investments) might be unavoidable in transitional financial systems. Regulators might want to pursue more adaptive capital adequacy regimes that recognize sustainability-linked investments as transitional exposures, such as by means of dynamic provisioning, gradual buffer modifications, or preferential risk-weighting regimes. To the bank managers, this highlights the need to ensure that liquidity planning and capital forecasting have sustainability agendas. Transparency of the greenwashing and ESG/digital disclosures and engaging supervisors as soon as possible can enable a trade-off between innovation and resilience.

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