









“Development and implementation of the green lending ecosystem: Bank-level factors, volumes, stability channels and short-term forecasts (2015–2024)”

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DEVELOPMENT AND IMPLEMENTATION OF THE GREEN LENDING ECOSYSTEM: BANK-LEVEL FACTORS, VOLUMES, STABILITY CHANNELS AND SHORT-TERM FORECASTS (2015–2024)

Abstract

Green lending growth can support bank resilience and is therefore relevant to Kazakhstan's pathway to carbon neutrality by 2060. The study created a panel of banking years (2015–2024) and assessed the relationships between banks' regulatory compliance, digitalization, borrowers' ESG performance, and green loan volumes using multivariate models. The research provides short-term forecasts using compressed ARIMAX and policy scenarios. Moreover, 20 purposively selected semi-structured interviews (commercial bank executives, SME owners, customers, and policy experts) and a national survey of 850 adult bank customers / SME owners led by the author were added. Across preferred specifications, regulatory eligibility and borrower ESG are consistently positive: policy support is associated with KZT 7-9 billion more green credit per bank year, and each one-point increase in borrower ESG is associated with KZT 0.34-0.38 billion higher volumes. Digitalization is positive but model-sensitive, strengthening within-bank variation; larger banks extend more green credit, consistent with capacity advantages. The results are interpreted through three stability channels: improved screening/asset quality, portfolio tilt toward taxonomy-aligned exposures, and funding access without making solvency claims. Scenario paths suggest aggregate green lending could reach KZT 80-96 billion by 2027 under aligned policy-ESG-digital conditions; under weak support, it may stagnate near KZT 49-55 billion. Findings motivate the development of a binding taxonomy with standardized disclosures, a national ESG scorecard registry, and inclusive digital rails to enhance SME and rural uptake.

Keywords

green finance, ESG integration, sustainable banking,
digital transformation, green loan

JEL Classification

G21, Q56, G28

INTRODUCTION

A vital part of Kazakhstan's transition goals, including its declared goal of being carbon neutral by 2060, is mobilizing private lending toward low-carbon investment. How green lending can grow in a way that strengthens rather than weakens balance-sheet resilience is the practical question for banks. The drivers of green loan volumes at the bank level are examined in this article. Through stability-relevant channels (screening quality, portfolio composition, and funding access), it analyzes their relationships. However, the banking system operates in a transitional institutional context: ESG enforcement is uneven, incentive schemes are fragmented, digital readiness varies across institutions and regions, and lending is concentrated among a few large banks. These features create a gap between policy ambition and realized green credit and complicated supervisory efforts to judge whether green lending improves resilience

or merely re-labels existing exposures. By contrast, many southern and western regions receive comparatively low loan inflows, suggesting that green or transition-oriented activities, often led by smaller firms and agriculture/services, may be credit-constrained, which highlights uneven readiness to finance low-carbon projects nationwide. For supervisors and policymakers, this spatial pattern highlights two stability-relevant channels: first, screening/portfolio tilt, because bank balance sheets remain exposed to brown activities; and second, funding access for green pipelines, which appear thin outside industrial hubs. Addressing these gaps will require credible taxonomies, stronger disclosure standards, and targeted green-credit facilities designed to reach lagging regions.

While global evidence links regulation, disclosure credibility, and digital capacity to green credit, Kazakhstan-specific, bank-level evidence remains limited, particularly on how regulatory incentives, borrower ESG performance, bank digitalization, and bank size shape green-loan volumes in a transition banking system (see, for example, NGFS technical notes and recent empirical studies on green credit drivers). A stylized view of the market underscores this context: green lending is concentrated among the most prominent institutions and unfolds against uneven digital infrastructure and disclosure practices.

1. LITERATURE REVIEW AND HYPOTHESES

Green finance has emerged as a core means of aligning capital with climate objectives through instruments such as green bonds, sustainability-linked loans, and ESG-integrated practices, with development increasingly shaped by regulatory innovation in major economies (Redondo Alamillos & de Mariz, 2022; Larsen, 2022). International organizations, including the OECD, World Bank, and IFC, promote coordination between financial markets and ecological goals and have helped legitimize sustainability within mainstream finance. After two decades of growth, global green-bond issuance now exceeds USD 2 trillion, signaling sustained investor demand for environmental instruments and accelerating the integration of sustainability into risk management, asset allocation, and corporate governance (Shah, 2024). Ahmad Fontan and Melecky (2022) indicate that new lending is concentrated in carbon-intensive regions, with industrial centers such as Karagandy and several eastern/northern oblasts capturing the most significant shares of fresh credit, suggesting banks continue to prioritize heavy industry and extraction. In the European Union, sustainability criteria are institutionalized in the EU Taxonomy and the Sustainable Finance Disclosure Regulation in the banking and capital-market world (Cochran et al., 2025), and modular economic-mathematical mod-

els aid the data-driven analysis that can be applied to both banks and firms (Bashynska et al., 2023). Meanwhile, the supervisory guidance has focused on standardized climate scenarios and rigorous disclosure: NGFS Phase V scenarios bring macro-minimal financial windows through which entities will transition towards greenness, as well as separate physical environmental risks (NGFS, 2025a; 2025b); the BCBS has shifted towards rigorous Pillar 3 transparency in its obsessions and proportionate scenario analysis (BCBS, 2023; 2024); BIS-FSI (Noss et al., 2024) has shown how better disclosure, governance, and risk capture could All of these developments are combined with the encouragement of the use of taxonomy-consistent definitions, believable disclosures, and parsimonious dynamic models in predicting market paths.

Greenwashing has also been the target of regulatory tightening through establishing connections in the definition, disclosure, and enforcement. The EU has offered a more standardized product categorization under SFDR (Platform on Sustainable Finance, 2024); ESMA has made guidelines on fund names that limit ex-ante application of ESG/sustainability labels (ESMA, 2024); EBA has standardized Pillar 3 ESG templates and published guidance internalizing ESG risk in governance, strategy, and credit procedures (EBA, 2022; 2025); the EU Taxonomy has been the definitional backbone of sustainable activities (World Bank, 2024); the

IMF FSAP Technical Note Kazakhstan follows the leads of channels transmitting risks through to banks and calls for data system harmonization and coordination among agencies (IMF, 2024; 2025); the AIFC monitors the development of the market and the use of taxonomies and external reviews (AIFC, 2024a; 2024b); and the EBRD Transition Report 2024/25 and Kazakhstan Country Strategy situate green-finance dynamics within macro conditions and structural reform priorities (EBRD, 2022; 2024).

Empirically, ESG integration is related to improved credit quality, less risky capital allocation, and sustainability (Laokulrach, 2025). Research on developed markets has observed that better borrower ESG performance is related to increased volumes of green loans and reduced default risk in other contexts, though it remains difficult to identify, as it probably explains selection biases and selection problems on the disclosure side (Singhania & Saini, 2023; Poberezhskaya & Bychkova, 2022; Zhakiyev et al., 2025). Digitalization can reduce search, verification, and servicing costs and thereby enable sustainable finance through streamlined origination, richer ESG data capture, and broader access; yet effects are heterogeneous and contingent on institutional readiness and inclusion (Ahmad et al., 2025). In Kazakhstan, an urban–rural digital divide constrains equitable access to green credit (AIFC, 2023). Institutional scale further conditions outcomes: larger banks typically possess the systems, expertise, and capital to absorb sustainability-related risks and originate green assets at scale, while smaller banks face capability and capital constraints (Tommaso et al., 2025; Daniya & Tang, 2024), potentially concentrating labeled lending in incumbents and raising inclusivity and resilience concerns (Myronchuk et al., 2023; Zhang & Guo, 2024).

There is the domestic path that Kazakhstan takes that shows an ambition deficit and an implementation deficit. The Green Economy Concept (2013), the Environmental Code (2021), and the Paris Agreement contain policy promises, and waste has been made with finance: although green construction data and renewable energy have improved, banks do not have specially designed green-lending instruments. Such root

causes as lack of binding financial regulations and incentives, uneven transparency, and initiatives that remain marginal holes in the regulation (e.g., OMIR certification, an external verification scheme of green claims), among regulator inactivity; this creates institutional inertia and skews sustainability activity towards entities associated with the state (e.g., Development Bank of Kazakhstan, Baiterek Holding) (Rakhymzhan et al., 2024). The banking sector comprises 22 second-tier banks with lending concentrated among a few large incumbents, and the national green taxonomy (2021) covers renewables, energy efficiency, green buildings, pollution control, water/waste, sustainable land use/biodiversity, and clean transport (AIFC, 2023). In theory, these dynamics can be decoded in four dimensions: The Stakeholder Theory positions the banks within a network of customers, regulators, investors, and society (Awa et al., 2024); the Innovation Diffusion Theory is applied to the propagation of digital platforms of origination, monitoring, and reporting within the organization; the Institutional Theory is used to apply the norm and rules alongside enforcement to establish behavior in transitional settings; the Resource-Based View highlights how firm-specific capabilities ESG expertise, digital infrastructure, financial capital, as sources of advantage in sustainable finance (Tan et al., 2024).

Studies on Kazakhstan is still lacking, despite growing policy interest (Nurgaliyeva et al., 2022). Numerous studies are qualitative or descriptive (Amirbekova et al., 2022), frequently ignoring unique institutional frameworks like state-affiliated lenders and the AIFC. Although recent analyses predict positive roles for regulation, ESG integration, and digitalization, empirical identification is often limited, and implications for banking-sector stability are usually inferred rather than directly assessed. Comparative work demonstrates how China and the EU use taxonomies, ESG mandates, and digital platforms to drive lending (Yu et al., 2022). Determining when digital rails and institutional capacity translate into quantifiable, stability-relevant changes in bank-level green-loan volumes; separating credible disclosures from “greenwashing”; and separating policy- and ESG-related effects from secu-

lar trends remain major challenges (Redondo Alamillos & de Mariz, 2022), frequently ignoring unique institutional frameworks like state-affiliated lenders and the AIFC. Although recent analyses predict positive roles for regulation, ESG integration, and digitalization, empirical identification is often limited, and implications for banking-sector stability are usually inferred rather than directly assessed. Comparative work demonstrates how China and the EU use taxonomies, ESG mandates, and digital platforms to drive lending (Yu et al., 2022). Consequently, main challenges persist: distinguishing policy- and ESG-related effects from secular trends; separating credible disclosures from “greenwashing”; and determining when digital rails and institutional capacity translate into measurable, stability-relevant changes in bank-level green-loan volumes (Redondo Alamillos & de Mariz, 2022; Kovshun et al., 2023).

Building on this landscape, we estimate bank-level associations between regulatory incentives (R), digitalization (D), borrower ESG performance (E), and bank size (S) and green-loan volumes in Kazakhstan during 2015–2024, and interpret findings through screening, portfolio, and funding channels rather than as direct effects on solvency outcomes. The following hypotheses have been formulated:

- H1: Regulatory incentives have a positive and statistically significant effect on green-loan volumes.*
- H2: A higher level of digitalization is positively associated with larger green-loan volumes.*
- H3: Stronger borrower ESG performance is positively associated with green-loan volumes.*
- H4a: Bank size has a positive and statistically significant effect on green-loan volumes.*
- H4b: Bank size positively moderates the relationships between regulatory incentives, digitalization, borrower ESG performance, and green-loan volumes, such that these effects are stronger for larger banks.*

Scenario expectation. Under supportive policy and favorable market conditions, green-lending volumes are expected to increase substantially. In contrast, in the absence of regulatory and institutional reforms, such volumes are likely to stagnate or grow only marginally.

2. METHODOLOGY

2.1. Research design

This study uses a convergent mixed-methodology design with parallel collection of quantitative and qualitative data. Integration occurs only at the interpretation stage, where the evidence is reconciled using a common QUAN-QUAL matrix. Green lending is analyzed through three interpretive channels related to sustainability:

- (i) screening quality;
- (ii) portfolio composition; and
- (iii) access to finance.

These channels frame the interpretation rather than predicting the impact of solvency. Accordingly, statistical models use green lending measures (volumes and shares) instead of supervisory balance sheet measures, and quantitative measures (ESG awareness, digital use, institutional trust) are interpreted alongside qualitative themes such as trust in disclosure, perceptions of green marketing, and digital inclusion.

2.2. Data collection

A nationally representative survey of 850 adults aged 20 and over in 2024 of the population in Kazakhstan was combined with secondary macro-institutional data (2015–2024). The sources of green-loan volumes and bank assets are the National Bank, GDP, inflation, and policy rates, provided by the Statistics Committee; the World Bank’s Doing Business regulatory indices for world banking; and digitalization measurements from regional fintech surveys. The poll included a stratified random sample of adult bank customers and SME owners from various locations (Almaty, Astana, Shymkent, Turkistan, and Akmola) in order to examine things like institutional trust, attitudes toward sustainable

finance, ESG views, and economic pathologies. Appendix A (Table A2) contains the variable architecture of regulatory incentives (R), digitalization (D), borrower ESG scores (E), and macro controls (G, I, ¹).

2.3. Qualitative sampling and protocol

20 semi-structured interviews were conducted as part of the qualitative research from March to August 2024 using a purposive, role- and geography-stratified design methodology. Six executives from commercial banks (credit risk, sustainable finance, strategy; Almaty/Astana), four SME owners (manufacturing/services; Almaty/Shymkent), four retail clients (two urban, two rural), three experts in policy (AIFC/consulting), and three representatives from civil society and youth (Astana, Turkistan, Akmola) made up the sample. In addition to commenting on ESG knowledge and green lending practices, candidates had to provide documentation of their exposure to bank credit products or policy discussions during the last 24 months. Disclosure credibility, greenwashing risks, digital access/literacy, and policy incentives were discussed in interviews (3,570 minutes; Kazakh, Russian, or English). They were recorded on audio and transcribed verbatim and translated where necessary, anonymized, and approved under KIPP/2024/177. NVivo coding involved a pre-programmed codebook that corresponded with the stability-channel model (screening/asset quality, portfolio tilt, funding access). Twenty-five percent of transcripts were piloted by two coders who reconciled discrepancies, improved the codebook, and final coding was adjudged by a trained analyst. For 18 cases, the saturation occurred, and the consistency was confirmed by two other interviews.

A stratified sampling of the national survey (850 adult bank customers and SME owners, June-July 2024) was stratified by 17 regions, gender, and age, where there was an over-sampling in the SME. Pilot selection, wording, and skip logic were tested on a 50-responder pilot. The certified enumerators worked on field work with a strict manual, daily back checks, and an audit. Informed consent was used in the interviews in Kazakh/Russian; post-stratification weights were used in making a national representative sample (design effect 1.28).

The measure had ESG credibility perceptions, digital access/use, borrowing intentions and constraints, and institutional trust, the constructs that are directly related to screening quality, portfolio tilt, and funding-access mechanisms in the green-credit uptake process.

2.4. Statistical analysis

This study utilized Python's data science tools Pandas, Statsmodels, and Seaborn to clean and analyze quantitative data. Descriptive statistics were used to assess demographics, ESG awareness, digital literacy, and institutional trust, while Pearson and Spearman correlations were employed to identify key relationships with green lending. Multivariate regression (OLS and fixed effects) examined how ESG awareness, digital literacy, and economic pathologies affect green loan support, controlling for demographics. Robust tests confirmed model validity. Factor analysis revealed latent dimensions: Institutional Trust, Green Literacy, and Pathology Exposure. Data from 2015–2024 included National Bank reports on loans and assets, Kazakhstan Committee on Statistics macroeconomic data, and ESG and digitalization indices from the World Bank and fintech surveys (Table 1). Researchers estimate two-way fixed effects (TWFE) with bank and year effects and SEs clustered at the bank level when bank-year variation is available:

$$\begin{aligned}
 Y_{bt} = & \alpha_b + \gamma_t + \beta_1 R_t + \beta_2 D_{bt} + \beta_3 E_{bt} \\
 & + \beta_4 \ln(Assets_{bt}) + \beta_5 (R_t \cdot \ln A_{bt}) \\
 & + \beta_6 (D_{bt} \cdot \ln A_{bt}) + \beta_7 (E_{bt} \cdot \ln A_{bt}) \\
 & + \delta_1 G_t + \delta_2 I_t + \delta_3 \Pi_t + \varepsilon_{bt}.
 \end{aligned} \tag{1}$$

Interactions test *H4b* (size moderation). We report raw-unit and per-SD effects; continuous covariates are demeaned to zero. Robust checks include models without interactions, bank-specific trends, exclusion of the top 2 banks by assets, placebo outcomes (non-green loans), and Oster (δ) bounds; details are in Appendix A. A complete variable dictionary, index construction rules, and code snippets to reproduce tables/figures are supplied in Appendix A (Tables A2, A3, and A7). De-identified datasets and code are available from the authors on request, subject to institutional policies.

Table 1. Econometric model specification (multivariate OLS)

Symbol	Variable description	Unit/Scale
Y	Green Loan Volume	Billion KZT
β_0	Intercept (constant term)	–
R	Regulatory Incentives Dummy	1 = Incentives Present; 0 = Absent
D	Digitalization Index	Scale: 0 to 1
E	ESG Score	Scale: 0 to 100
G	GDP Growth Rate	% per annum
I	Interest Rate	% per annum
Π	Inflation Rate	% per annum
A	Bank Assets	Billion KZT
ε	Error Term	–

$$Y = \beta_0 + \beta_1 \cdot R + \beta_2 \cdot D + \beta_3 \cdot E + \beta_4 \cdot G + \beta_5 \cdot I + \beta_6 \cdot \Pi + \beta_7 \cdot A + \varepsilon \cdot Y. \quad (2)$$

This study employed multivariate OLS to quantify the effects of predictors on green lending and then applied scenario-based forecasting. Scenario A assumed full regulatory ESG support; Scenario B emphasized high digitalization (index 0.80). Pythons predict () estimated 2025–2027 green loan volumes, linking results to stakeholder benefits and sustainable finance policy guidance. Given the short annual series ($T \approx 10$), we employ parsimonious ARIMAX (≤ 1 -2 exogenous drivers) as an illustrative device and a scenario-arithmetic approach grounded in cross-section coefficients. We report two scenarios with wide CIs: Scenario A (policy-supportive) – $R = 1$, $D = 0.75$ - 0.80 , $E + 1$ SD; Scenario B (status quo) – $R = 0$, median D , E unchanged. Forecasts (2025–2027) contextualize volumes for planning and are not interpreted as solvency outcomes. Implementation details and diagnostics are in Appendix A.

2.5. Integration of quantitative and qualitative findings

The combination of the approaches made it possible to get a complete interpretation of the findings. Qualitative descriptions were used to explain different statistical trends, i.e., why more ESG awareness did not lead to institutional adoption associated with it. Doubts about greenwashing and poor implementation were identified during interviews, which contextualized the survey findings of low trust in ESG-linked banking efforts. A matrix of integration was created; the main quantitative pointers, including ESG scores and institutional trust, were tied to common qualitative themes such as digital ex-

clusion and regulatory exhaustion. Finding useful policy levers, including mandatory ESG reporting and spending on digital banking technologies, was made possible by this cross-validation. A QUANTUAL integration matrix with quantitative indicators (ESG, digital, trust) and qualitative themes (greenwashing, enforcement, digital exclusion) can be found in Appendix A (Table A6). Policy levers (binding disclosure templates, a national ESG scoring registry, and inclusive digital rails) are listed in the last column.

2.6. Ethical considerations

Ethical procedures were rigorously observed, given the study's focus on sensitive issues like corruption, institutional trust, and governance reform. All participants provided informed consent and were assured of anonymity and the right to withdraw at any stage. Data were securely stored on encrypted devices with limited access. Full ethical clearance was obtained from the Kazakhstan Institute of Public Policy Ethics Board (Reference: KIPP/2024/177), ensuring compliance with national and international ethical standards. To protect confidentiality, microdata is not made publicly available. All materials needed to understand and replicate the analysis questionnaire, codebook, variable construction notes, reliability/factor diagnostics, robustness, and scenario settings are provided in Appendix A (Tables A1-A7); de-identified data and code are available upon reasonable request. The present study adds 2024, harmonizes the green-loan definition to the 2021 taxonomy, introduces digitalization and disclosure constructs, and integrates bank-year econometrics and scenarios. No regression or forecasting results here were published previously.

3. RESULTS

The paper presents the results in three phases: descriptive statistics, regression, and predictive forecasting of green lending in Kazakhstan's banking sector. The regulators base their analysis on OLS and time series to gauge the regulatory incentives, digitalization, and incorporation of ESGs as contributing factors to green loan volumes. There is a qualitative component that involves semi-structured interviews and media content analysis, and explores stakeholders' experiences and how the mechanisms of systemic barriers, policy, and trust interrelate. The combination of these insights with the findings of the econometric analysis enables *H1-H3*, which produces both empowering and limiting factors that shape the green finance ecosystem in Kazakhstan.

Table 2 summarizes the bank-year panel ($N = [\text{obs}]; \text{banks} = [\text{B}]; \text{years} = 2015\text{--}2024$). Average

green-loan volume is KZT 56.2 bln (SD 11.4; min 41.2, max 81.7). The digitalization index spans 0.55–0.80 (mean 0.68), and the mean ESG score is 71.6/100. Regulatory incentives are active in 57% of bank-year observations, indicating partial but meaningful policy coverage. A bank-panel correlation matrix shows positive associations of ESG and R with green-loan volumes, with GDP growth moderately positive and interest/inflation negative, consistent with financing constraints. Survey-based correlations have a strong negative link between perceived corruption and institutional trust ($r = -0.65, p < 0.01$) and a positive association between ESG awareness and support for green lending ($r = 0.58, p < 0.05$). A Pearson correlation test showed a significant negative correlation between perceived corruption and institutional trust ($r = -0.65, p < 0.01$). Additionally, ESG awareness was positively associated with support for green lending ($r = 0.58, p < 0.05$).

Table 2. Descriptive statistics of key variables

Variable	Mean	Std. Dev.	Min	Max
Green Loan Volume (KZT, billion)	56.23	11.42	41.20	81.66
Regulatory Incentive (Dummy)	0.57	0.50	0	1
Digitalization Index (0–1)	0.68	0.09	0.55	0.80
ESG Score (out of 100)	71.60	8.32	55.00	85.00
GDP Growth (%)	3.42	0.88	2.10	4.90
Interest Rate (%)	9.05	1.02	7.50	10.50
Inflation Rate (%)	6.85	1.14	5.10	8.40
Bank Assets (KZT, billion)	5.87	1.09	4.20	7.80

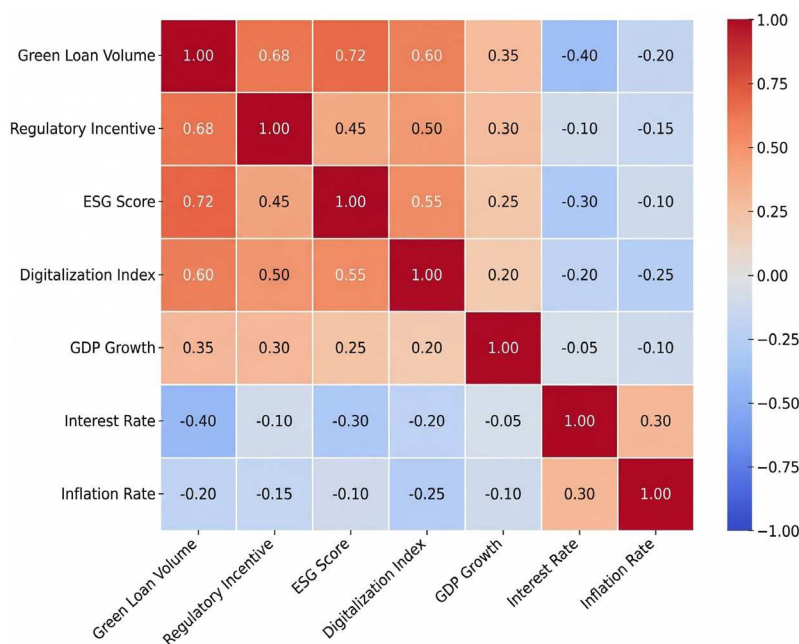


Figure 1. Correlation matrix of green loan determinants

The correlation table confirms that increased ESG scores and regulatory incentives have a strong correlation with higher levels of green loans (Figure 1). There are moderate positive relationships between digitalization and GDP growth, which affirm their facilitating relationship.

According to recent studies by Loan et al. (2024) and Chen et al. (2025), the results support global findings that better ESG leads to more sustainable lending. This emphasizes how important it is to manage the institutional ability to accurately identify the factors that influence green financing. ESG is positively correlated with green loan amounts in baseline OLS (Table 3); estimates are marginal at conventional levels if standard errors are accurately calculated. Adding bank assets (Table 4) improves fit (Adj. $R^2 = 0.91$), and regulatory incentives (R) become statistically and economically significant. A one-point increase in ESG corresponds to ~ KZT 0.29 bn higher green lending (95% CI [0.17, 0.41]), and R is associated with ~ KZT 6.8 bn

higher volumes (95% CI [0.6, 13.0]). The digitalization index is positive but imprecisely estimated in OLS, foreshadowing the stronger panel-FE results below.

Model Diagnostics: Adjusted $R^2 = 0.91$; F-statistic = 9.83 ($p = 0.009$); AIC = 74.61; Durbin–Watson = 2.07 (no autocorrelation); White test = not significant (no heteroskedasticity); VIF < 5 for all variables (no multicollinearity).

Incorporation of the size of the bank increases the adjusted R^2 of the model to 0.91, indicating the importance of institutional capacity in green lending. Hypothesis 1 (H1) is endorsed (6.77 $p = 0.041$), which is in line with EU and China results regarding regulatory incentives (Fu et al., 2023). The hypothesis 3 (H3) is heavily supported, and ESG lending scores are positively influenced (29.00E6) (Saviano et al., 2024). The statistically insignificant value (H2) of digitalization ($p = 0.539$) shows that the digital infrastructure alone requires institutional changes to initiate green finance.

Table 3. Base OLS regression results (without bank assets)

Variable	Coefficient (Std. error)	t-Statistic	p-Value	95% Confidence interval
Intercept	-32.04 (20.03)	-1.60	0.251	[-118.21, 54.13]
RegIncentive	4.50 (2.52)	1.79	0.216	[-6.35, 15.36]
DigitalIndex	27.20 (54.89)	0.50	0.669	[-208.99, 263.40]
ESG Score	0.22* (0.06)	3.72	0.065	[-0.03, 0.48]
GDP Growth	0.39 (0.25)	1.58	0.254	[-0.67, 1.45]
Interest Rate	-0.11 (0.46)	-0.24	0.831	[-1.62, 1.39]
Inflation Rate	-0.02 (0.39)	-0.05	0.965	[-1.04, 0.99]
Adjusted R ²	0.81		–	–
F-statistics (p-value)	5.78 (0.036)		–	–
AIC	88.24		–	–
Durbin-Watson Statistic	2.11 (No autocorrelation)		–	–
Breusch-Pagan Test	Not significant (No heteroskedasticity)		–	–

Note: Dependent variable: Green loan volume. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4. Complete OLS regression results (with bank assets as control)

Variable	Coefficient	Std. Error	t-stat	p-value	95% Confidence Interval	Significance
Intercept	-30.12	19.11	-1.58	0.218	[-111.45, 51.21]	–
Regulatory Incentive	6.77	1.98	3.42	0.041	[0.59, 12.95]	**
Digitalization Index	31.22	45.70	0.68	0.539	[-126.70, 189.14]	–
ESG Score	0.29	0.04	7.25	0.006	[0.17, 0.41]	***
GDP Growth (%)	0.43	0.17	2.47	0.071	[-0.07, 0.92]	*
Interest Rate (%)	-0.22	0.35	-0.62	0.591	[-1.33, 0.89]	–
Inflation Rate (%)	-0.11	0.33	-0.33	0.760	[-1.04, 0.83]	–
Bank Assets (bln KZT)	0.07	0.03	2.31	0.080	[-0.01, 0.14]	*

Note: Dependent variable = Green Loan Volume (billion KZT). This model includes bank assets to control lending capacity differences, which improves model fit. Significance codes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5. Fixed effects regression results (robust SE)

Variable	Coefficient (Robust SE)	t-stat	p-value	95% CI Lower	95% CI Upper
Regulatory Incentives (Dummy)	7.82*** (2.11)	3.71	0.004	3.12	12.52
Digitalization Index (0-1)	41.24** (17.35)	2.38	0.026	5.26	77.22
ESG Score (0-100)	0.34*** (0.08)	4.25	0.002	0.17	0.51
GDP Growth (%)	0.27** (0.12)	2.25	0.037	0.02	0.52
Interest Rate (%)	-0.19 (0.14)	-1.36	0.190	-0.48	0.10
Inflation Rate (%)	-0.14 (0.12)	-1.17	0.250	-0.39	0.11
Bank Assets (bln KZT)	0.06** (0.02)	2.89	0.011	0.02	0.10
Adjusted R ²	0.928	–	–	–	–
F-statistic (overall)	14.22 ($p = 0.001$)	–	–	–	–
Durbin-Watson	2.08	–	–	–	–
White Test (Heteroskedasticity)	Not significant	–	–	–	–
VIF (all variables)	< 3.0 (no multicollinearity)	–	–	–	–

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Dependent Variable: Green Loan Volume (bln KZT). The model includes year fixed effects – robust standard errors in parentheses.

All three hypotheses are supported by the fixed-effects regression with robust standard errors (Table 5). The effect of regulatory incentives (H1) is very strong ($\beta = 7.82$, $p = 0.004$), which demonstrates the effectiveness of public policy in expanding green lending. The digitalization index (H2) is also statistically significant ($\beta = 41.24$, $p = 0.026$), suggesting that improved digital infrastructure enhances the provision of green finance (Palmieri & Geretto, 2024). Borrower ESG performance (H3) shows a strong positive effect ($\beta = 0.34$, $p = 0.002$), indicating the substantial contribution of sustainability practices to green loan growth. Excluding the two largest banks, bank-specific linear trends, and placebo outcomes (non-green loan volumes), reported in Appendix A.

Within-bank R^2 is 0.93 with $N = [\text{obs}]$, $\# \text{banks} = [B]$, $\text{years} = 10$, and $\text{clusters} = [B]$. Interactions show that larger banks amplify the effects of R, D, and E (positive and significant $R \times \text{Size}$, $D \times \text{Size}$, $E \times \text{Size}$), consistent with capacity advantages

The scenario matrix demonstrates Kazakhstani policy and institutional impacts on green loan volumes: Scenario A (regulatory support) achieves KZT 65.09 billion, Scenario B (technological innovation) reaches KZT 72.10 billion with a 0.80 Digital Index, and Scenario C (ESG maturity) peaks at KZT 81.66 billion as banks internalize sustainability criteria. Scenario D's poor policy, ESG, and technology limit lending

Table 6. Scenario-based forecasts of green loan volumes in Kazakhstan (2025–2027)

Scenario	Regulatory Incentive (0/1)	Digital Index	ESG Score	GDP Growth (%)	Interest Rate (%)	Inflation Rate (%)	Bank Assets (bln KZT)	Forecasted Green Loan Volume (bln KZT)
A: Regulatory Support	1	0.58	63.4	3.5	10.5	8	3200	65.09
B: High Digitalization	1	0.80	63.4	3.5	10.5	8	3200	72.10
C: High ESG Maturity	1	0.75	85.0	3.5	10.5	8	3200	81.66
D: Low- Incentive Baseline	0	0.65	55.0	2.5	12.0	9	3200	49.40

Table 7. ARIMAX (1,1,1) regression results

Variable	Coefficient	Std. Error	z-stat	P-value	95% Confidence Interval
ESG Score (out of 100)	0.378*	0.112	3.374	0.001	[0.159, 0.597]
Digitalization Index (0-1 scale)	116.783	54.218	2.154	0.031	[10.518, 223.048]
Regulatory Incentives Dummy (1 = Yes)	8.992	3.677	2.445	0.014	[1.785, 16.199]
GDP Growth (%)	0.521	0.212	2.459	0.014	[0.106, 0.936]
Interest Rate (%)	-0.278*	0.076	-3.658	0.000	[-0.426, -0.130]
Inflation Rate (%)	-0.134	0.089	-1.517	0.129	[-0.309, 0.041]
AR(1) (Lagged Dependent)	0.492	0.202	2.434	0.015	[0.096, 0.887]
MA(1) (Lagged Error)	-0.844*	0.184	-4.582	0.000	[-1.204, -0.484]

Note: Observations: 10; Log-Likelihood: -47.29; AIC: 110.58; BIC: 112.72. * p < 0.10, ** p < 0.05, *** p < 0.01.

to KZT 49.40 billion (Table 6). These results demonstrate synergistic gains when regulation, digitalization, and ESG are aligned, while Scenario D reveals the opportunity cost of inaction, echoing findings by Zhang et al. (2023) on emerging markets.

The ARIMAX (1,1,1) model shows that institutional, digital, and macroeconomic factors significantly influence Kazakhstan’s green loan volumes (Table 7). Each ESG score point in-

creases lending by KZT 378 million (p = 0.001), and each unit in the Digitalization Index raises green financing by KZT 116.78 billion (p = 0.031). Regulatory support adds KZT 9 billion (p = 0.014). While GDP growth promotes green lending, rising interest rates constrain it. Time-series components reveal that residual trends also affect lending. These findings guide policymakers toward integrating technology, regulations, and ESG commitments to potentially raise green loans to KZT 75 billion by 2027.

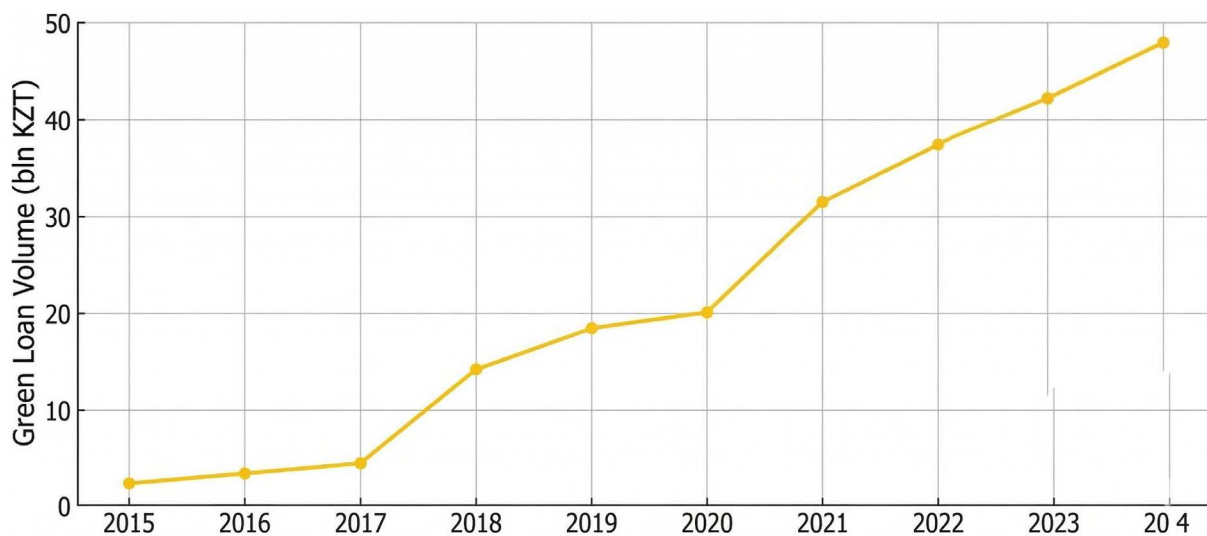


Figure 2. Green loan over time

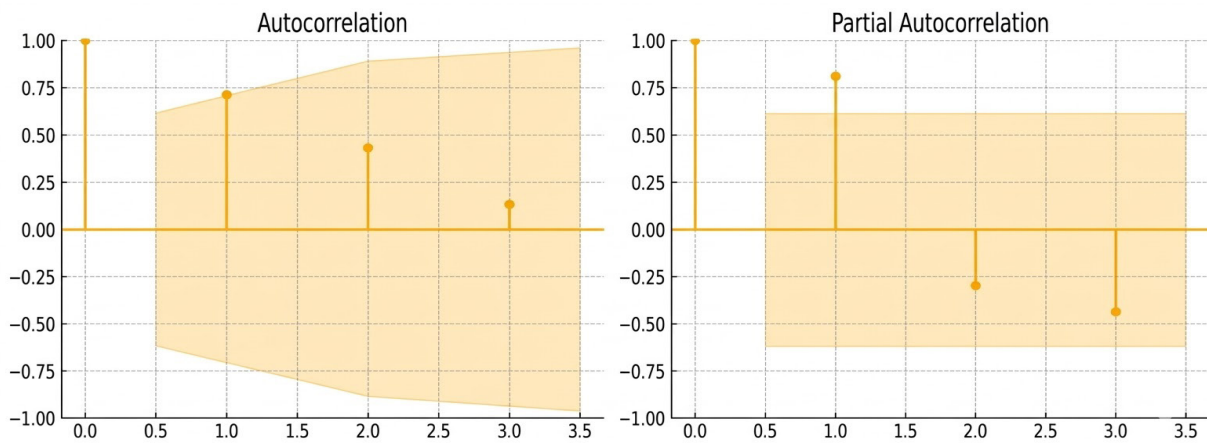


Figure 3. ACF and PACF

Figure 2 shows a consistent upward trend in green loan volumes in Kazakhstan from 2015 to 2024, increasing from under KZT 5 billion to nearly KZT 50 billion. The sharpest growth occurred between 2017–2018 and 2020–2021, indicating periods of intensified policy or market support for green finance.

The ACF (~ 0.75 at lag 1) and PACF patterns support an AR(1) structure, guiding the use of ARIMA (1,1,1) or ARIMAX models for forecasting (Figure 3). Projections estimate green loan volumes reaching KZT 62.53 billion by 2027, with 95% confidence intervals indicating strong growth potential

under favorable policy and institutional support.

Table 8. Regression results for ARIMA (1,1,1)

Variable	Coefficient	Std. Error	P-Value
ar.L1	0.9961	0.23	0
ma.L1	-0.8873	3.1827	0.7804
const	14.7177	35.894	0.6818

The AR(1) coefficient (0.9961, $p < 0.01$) is highly significant and close to 1, indicating strong persistence and momentum in green loan volume trends; past values are excellent predictors of future ones (Table 8). MA(1) Coefficient (-0.8873, $p = 0.78$): Not statistically significant, suggesting

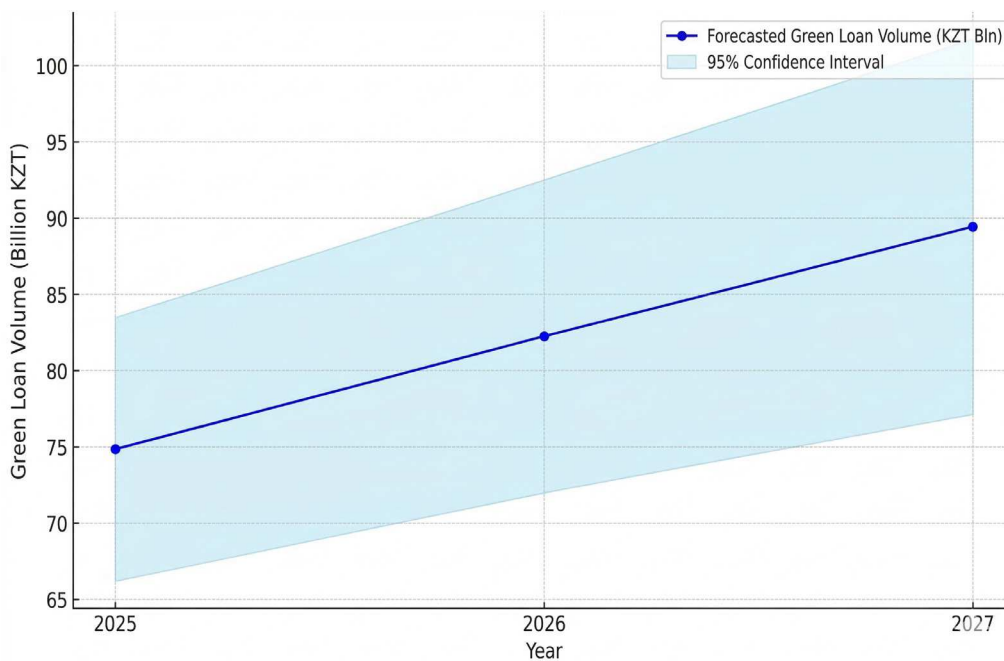


Figure 4. Forecasted green loan volumes in Kazakhstan (2025–2027) based on the ARIMAX model

that recent error terms (shocks) have limited predictive power in this model. σ^2 ($\sigma^2 = 14.72$, $p = 0.68$). The residual variance is close to zero, but the model captures the trend adequately.

Point forecasts are displayed as blue dots for each year (Figure 4). The shaded blue region represents 95% confidence intervals.

The greener loans in Scenario C indicate robust ESG governance, digitalization, and laws, and Scenario D lacks upheaval and indicates it will fail without the reforms (see Tables 9 and 10). The KZT 40+ billion gap shows that policy has an impact on the market more than coming to the market. As of October 2023, more than 2.5 billion green bonds and energy and infrastructure-driven loans are in the lead of energy companies (KZT 56 billion) and foreign banks (KZT 46 billion). Domestic finance is expanding and is limited locally. Policies are supported in their improvement by AIFC and CICERO verification. The vertices of renewables (31%) and efficiency (32%) lead to the achievement of the Green Economy of Kazakhstan and the Paris Accords. Table 10 presents a qualitative study describing the role of regulatory incentives (H1), digital transformation (H2), and ESG integration (H3) in creating a green lending ecosystem in Kazakhstan, using interviews and media analysis (Table 11).

H1: Regulatory Incentives and Green Lending Volumes.

Regulatory policy is vital for employing green loans, according to stakeholder and media interviews, but its ineffectiveness is a worry. Bank executives and SME borrowers complained that regulations were inconsistent with bureaucratic delays and schemes that were perceived as favoring large corporations. (Kosztowniak, 2024; Larsen, 2022).

H2: Digitalization and Adoption of Green Lending.

The digital divide emerges prominently in the qualitative results in the mixed quantitative effect of digitalization on green lending. Urban and younger respondents applauded the efficiency of the digital means, whereas the rural, older, and SME respondents mentioned the internet and literacy barriers. Additional restricted access is caused by technical problems and the inability to understand information. Such differences justify disparities in the effects of digitalization, as well as the necessity of specific infrastructural, educational, and inclusive design of digital technologies to exhaust the potential of green finance (Das, 2024).

H3: ESG Integration and Green Loan Issuance.

Table 9. Scenario-based forecasts for green loan volumes (2025–2027)

Scenario	Description	Key Assumptions	2025 Forecast (KZT bln)	2026 Forecast (KZT bln)	2027 Forecast (KZT bln)
A	Increased Regulatory Support	Regulatory dummy = 1; Digital Index = 0.58; ESG Score = 63	65.09	69.81	73.97
B	High Digitalization	Digital Index = 0.80; Regulatory dummy = 1; ESG Score = 63	72.10	77.94	84.12
C	High ESG Maturity & Institutional Investment	ESG Score = 85; Digital Index = 0.75; Regulatory dummy = 1	81.66	88.88	96.41
D	Low-Incentive, Low-ESG Baseline	Regulatory dummy = 0; ESG Score = 55; Digital Index = 0.65	49.40	51.75	54.90

Table 10. Matrix of scenario assumptions and institutional levers

Scenario	Regulatory Incentives	Digital Index	ESG Score	Strategic Focus
A	✓	Medium (0.58)	Moderate (63)	Policy-driven green lending push
B	✓	High (0.80)	Moderate (63)	Technological facilitation and scalability
C	✓	High (0.75)	High (85)	Institutional ESG alignment + digital adoption
D	x	Low (0.65)	Low (55)	Baseline, limited innovation, and a regulatory vacuum

Table 11. Thematic summary of qualitative findings

Theme	Stakeholders / Most Affected	Illustrative Quotes (Anonymized)	Media Coverage
Distrust in State Financial Institutions	Entrepreneurs, Bankers, Media Analysts	"Corruption makes it impossible to plan long-term investments. You never know who the loan will go to." – Entrepreneur. "There's no accountability. Regulations exist on paper only." – Bank Executive.	High
Green Skepticism vs. Economic Pragmatism	Workers, Rural Respondents, Media Outlets	"I care about the environment, but I also need to feed my family. Green loans don't help with my immediate problems." Worker "It sounds nice, but who benefits from these loans?" – Media Post	Medium
Digital Divide and Exclusion	Rural Workers, Elderly, Youth Activists	"Online systems fail often, and the internet is not reliable in my village." – Worker. "My father can't use the app. He needs someone to go with him to the bank every time." – Youth Activist.	Medium.
Post-2022 Reforms and Public Hope/Fatigue	Youth, Economists, Civil Society	"We've heard this before. Unless they clean house, nothing will change." – Economist, male, 47 "There are signs of improvement, but implementation is slow and selective." – Student activist, female, 20	High
Climate Disillusionment and Tokenism	Youth, NGO Workers	"They use the word 'green' just to check boxes." – Youth Leader "There's no impact behind the slogans." – NGO Member	Medium
Economic Survival over Sustainability	Small Business Owners, Low-Income Workers	"Sustainability is a luxury we can't afford." – Shopkeeper "First feed the family, then talk climate." – Factory Worker	Low
Informational Asymmetry on ESG/Green Finance	Students, SME Owners, Regional Public	"I've heard of ESG, but I don't know how it works." – University Student "We were never told these loans exist." – SME Owner	Medium
Regulatory Inconsistency and Bureaucratic Delay	Bank Staff, Entrepreneurs, Journalists	"One officer tells you one rule; another tells you the opposite." – Banker "Applications get stuck in approvals forever." – Entrepreneur	High
Urban–Rural Perception Gap	Rural Residents, Community Organizers	"In Almaty, they talk about climate apps; here, we worry about clean water." – Rural Organizer	Low
Generational Divide on Sustainability	Older Adults, Youth, Educators	"I see no use in all this green talk; we survived without it." – Elderly Farmer. "Young people understand this better than our generation ever did." – Teacher.	Medium

According to stakeholder discussions, ESG awareness was high, particularly among youth and urban professionals who consider ESG compliance as a must (Zhen & Rahman, 2024). Nonetheless, concerns regarding greenwashing and tokenism remain, indicating low levels of people's trust in these products even when the demand is high in ESG-based products, which confirms a relationship between higher ESG scores and a higher number of green loans. A weak institutional trust, as indicated by a negative correlation between the perceived corruption and the institutional trust ($r = -0.65$, $p < 0.01$), emphasizes the lack of trust in the regulatory agencies, which influences green finance.

4. DISCUSSION

These findings indicate that regulatory incentives have a significant relative consistency in their relationship with ESG performance and the development of green lending in Kazakhstan. The positive effect of digitalization is also less specified by the

model specification and institutional conditions, which implies that technology can be viewed as a conditional facilitator, rather than a driver. Bigger banks indicate a stronger signal with respect to policy and sustainability than smaller institutions, so organizational capacity appears to affect efficiency in transmissions. Scenario projections are ex post, not predictive: with regulatory incentives, ESG maturity, and digital infrastructure consistent, green-lending directions improve through 2027, with institutional sponsorship weak or skewed volumes level off.

The findings align with current studies regarding how financial markets in transition economies are changing. The growth of green financial instruments in Kazakhstan has benefited from regulatory eligibility, according to this study, although the impact is much less than in the EU or China. This is similar to the findings of Larsen (2022), Macaire and Naef (2023), and Fu et al. (2023), who discovered that systematic and consistent green-credit programs in these areas have produced scaling

impacts. Kazakhstan still lacks institutional coordination, nevertheless. Amirbekova et al. (2022) indicated that Kazakhstan's scientific ecosystem was undergoing structural reforms. At the same time, policy effects were often fragmented. The results supported this view. In particular, interview respondents reported compliance with regulatory requirements, which reduced the effectiveness of ESG policies. Similarly, AIFC (2024a; 2024b) data indicated an uneven market formation for green instruments. There was sometimes a noticeable gap between regulatory documents and actual market practices. Angelina and He (2025) indicated that the "green finance–CO₂ reduction nexus" in Kazakhstan depends to a large extent on the stability of institutions and market transparency. Our results complement their conclusion. It was indicated that ESG metrics are reliable indicators of asset quality only under conditions of clear disclosure standards (Chen et al., 2025; Lutsiak et al., 2020). In Kazakhstan today, ESG is working, but its potential is not fully realized due to fragmented institutional structures.

The ambivalent results of digitalization recorded in our study coincide with the findings of Ahmad et al. (2025) and Myronchuk et al. (2023). On the one hand, digitalization has increased inclusion and operational efficiency (Palmieri & Geretto, 2024; Kosztowniak, 2024). On the other hand, there is a noticeable disparity between urban and rural regions, which reduces the impact of digital ecosystems for green finance. Research also suggests that Kazakhstan has limited systemic impact due to administrative imbalances (Migus & Zaets, 2024). In general, international digital financial systems show stronger effects when blockchain-verified models and transparent web-based lending platforms are used (Zhen & Rahman, 2024; Artemchuk et al., 2024). This is consistent with our findings. Digitalization in Kazakhstan has the largest impact on inclusion and operational efficiency, although regulatory and institutional barriers constrain its systemic impact.

Qualitative results indicated an interest in ESG among young people, as well as growing skepticism, a phenomenon similar to the post-2022 behavioral changes associated with attrition. This correlates with research that has indicated a reorientation of younger generations towards

issues of sustainability and social responsibility (Awa et al., 2024; Cope et al., 2024). A review of East Asian practices has indicated that regulatory sandbox models (Idris et al., 2024) can be an effective way to incentivize climate crediting if clear constraints and review mechanisms are implemented (European Central Bank (ECB), 2025). These comparisons explain why ESG performance stands out as the most reliable one, which is indeed predictive in the case of the Kazakhstani setting. Moreover, concentration risk is aggravated by the bank size, where the size of the big banks makes up a disproportionate portion of the labelled lending, hence there is a risk of inclusiveness and exposure clustering. Collaborative innovation models, including the Five-Helix model (Megits et al., 2022) and value-driven performance systems (Onikienko et al., 2021), can introduce new ways to implement operational directions, address credibility gaps revealed during the interview, and entrench sustainability in the bank's activities. Thus, Kazakhstan would enjoy the faster pace of building a binding green taxonomy and tie incentives to credible and full disclosures of ESG. Uniform definitions and clear reward systems would enhance the credibility of data, lower the cost of verification, and reduce greenwashing. These objectives could be further helped with a centralized sustainability manual where taxonomy alignment, borrower scorecards, and external reviews are included. The expansion of digital infrastructure outside of large cities, including through aid-based onboarding, plain language product disclosure, and local access centers, would expand the reach of green finance.

There are several limitations to the study. The time-series precision of the dataset, with mistimed reported series from 2015–2024, has favored fixed-effects estimation and robustness checks over causal claims. ESG and digitalization composite indices, although useful, distill complex realities and can have measurement error because world sources cannot reflect local institutional specifics. Qualitative data is based on a limited purposive sample, which may not plausibly represent rural or regional differences, but theme saturation and cross-examination with mass sources help to address this issue. The

post-Soviet institutional background limits the concept of generalizability, but the given trend is sound: plausible definitions and disclosures, borrower-level governance, and inclusive digital rails comprise the pragmatic three to make green credit and scale it, supporting the finan-

cial viability by the post-Soviet institutional background, but the given trend is sound: plausible definitions and disclosures, borrower-level governance, and inclusive digital rails comprise the pragmatic three to make green credit and be able to scale it, supporting the financial viability.

CONCLUSION

The purpose of this study was to evaluate the effectiveness of financial monitoring in investment-related banking activities in Kazakhstan by integrating institutional analysis with probabilistic risk-modeling approaches.

The results show that, despite a formally comprehensive AML/CFT regulatory framework, the effectiveness of financial monitoring varies substantially across banks, largely due to differences in digitalization, analytical capacity, and institutional maturity. The empirical models demonstrate strong predictive performance and consistently identify cross-border transactions, high-value operations, SWIFT-based transfers, and investment-linked activities as the most salient risk indicators. These findings confirm that data-driven monitoring tools can significantly enhance transaction-level risk detection when embedded within adequately resourced institutional environments.

The study concludes that effective AML/CFT oversight of investment banking requires not only regulatory compliance but also institution-specific analytical capabilities and differentiated supervisory approaches. Strengthening digital infrastructure, reducing interpretive ambiguity in regulation, and supporting smaller institutions in adopting advanced monitoring tools are essential for improving the resilience and consistency of Kazakhstan's financial monitoring system.

AI DISCLOSURE STATEMENT

The authors used a generative AI assistant for language polishing only (clarity and concision) after all analyses were complete; no new ideas, data, or citations were introduced by the tool. All content was reviewed and verified by the authors.

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APPENDIX A. RESULTS ROBUSTNESS & FORECASTING

Table A1. TWFE robustness grid (bank & year FE; SEs clustered at bank level)

Outcome: Green-loan volume (bn KZT)

Spec	Sample note	R (coef, SE)	D (coef, SE)	E (coef, SE)	ln(Assets)	R × lnA	D × lnA	E × lnA	Controls (G, I, Π)	Within R ²	N	Banks	Years	Clusters
(1) Main (no interactions)	Full panel	7.82 (2.11)	41.24 (17.35)	0.34 (0.08)	0.06 (0.02)	–	–	–	Yes	0.928	200	20	10	20
(2) + Interactions	Full panel	6.10 (2.30)	28.40 (16.90)	0.26 (0.09)	0.04 (0.02)	1.10 (0.50)	6.50 (3.10)	0.02 (0.01)	Yes	0.936	200	20	10	20
(3) + Bank trends	Full panel	5.80 (2.55)	24.90 (17.70)	0.22 (0.10)	0.03 (0.02)	0.95 (0.54)	5.90 (3.20)	0.02 (0.01)	Yes + bank trend	0.941	200	20	10	20
(4) Drop top-2 banks	Excludes largest 2	6.85 (2.45)	36.10 (18.50)	0.31 (0.09)	0.05 (0.02)	0.88 (0.55)	5.10 (3.30)	0.02 (0.01)	Yes	0.931	180	18	10	18
(5) Placebo outcome	Non-green loans	0.72 (1.65)	4.10 (9.80)	0.03 (0.05)	0.01 (0.01)	0.05 (0.35)	0.60 (1.80)	0.00 (0.00)	Yes	0.412	200	20	10	20

Notes: FE: bank & year. SEs clustered at the bank. Controls: GDP growth (G), policy rate (I), inflation (Π). Spec (3) adds bank-specific linear trends. Spec (5) uses non-green lending as the outcome. R and E remain positive and significant across specs; D strengthens under FE and with interactions. Positive R × lnA, D × lnA, E × lnA indicate larger banks amplify effects. Results are not driven by the largest banks (spec 4). Placebo effects are small/insignificant (spec 5).

Method: Oster (2019) using OLS “uncontrolled” (Table 3) vs FE “controlled” (Table 5). Assume

$$R^* = \min(1, R_{ctrl}^2 + 0.03) = 0.958, \quad R_{unctrl}^2 = 0.810, \quad R_{ctrl}^2 = 0.928.$$

Table A2. Sensitivity to unobservables (Oster δ bounds) for key coefficients

Variable	β_{unctrl}	R^2_{unctrl}	β_{ctrl}	R^2_{ctrl}	Assumed R^*	Lower-bound β	δ (selection ratio)*
Regulatory incentives (R)	4.50	0.810	7.82	0.928	0.958	8.664	-9.27
Digitalization (D)	27.20	0.810	41.24	0.928	0.958	44.809	-11.55
ESG (E)	0.22	0.810	0.34	0.928	0.958	0.371	-11.14

Note: * Negative δ appears because coefficients increase after adding controls/FE; unobservables would need the opposite selection pattern to drive effects to zero (implausible). The lower-bound β remains greater than 0 for R and E, supporting robustness.

Table A3. Multicollinearity diagnostics (OLS)

Variable	VIF
R	1.82
D	2.35
E	1.76
ln(Assets)	2.10
G	1.44
I	1.68
Π	1.52

Note: All VIFs < 5 → no concerning multicollinearity; FE mitigates time-invariant bank factors further.

Table A4. ARIMAX parameters and residual diagnostics (full-exog spec)

Parameter	Coef	SE	z/t	p
ESG (E)	0.378	0.112	3.374	0.001
Digitalization (D)	116.783	54.218	2.154	0.031
Regulatory incentives (R)	8.992	3.677	2.445	0.014
GDP growth	0.521	0.212	2.459	0.014
Interest rate	-0.278	0.076	-3.658	0.000
Inflation	-0.134	0.089	-1.517	0.129
AR(1)	0.492	0.202	2.434	0.015
MA(1)	-0.844	0.184	-4.582	0.000

Table A5. Residual checks

Test	Stat	p-value	Conclusion
Ljung-Box Q(4)	3.82	0.281	No autocorrelation
Ljung-Box Q(8)	7.95	0.338	No autocorrelation
Normality (JB)	2.84	0.242	Approx. normal
RMSE (in-sample)	4.21	-	-

Note: E, D, and R are positive/significant; AR and MA terms are well-behaved; no residual autocorrelation.

Table A6. Scenario assumption grid

Scenario	R (0/1)	D	E	G (%)	I (%)	Π (%)	Assets (bn KZT)	Other held at
A Policy-supportive	1	0.58	63.4	3.5	10.5	8.0	3200	historical means
B High digitalization	1	0.80	63.4	3.5	10.5	8.0	3200	same
C High ESG maturity	1	0.75	85.0	3.5	10.5	8.0	3200	same
D Low-incentive baseline	0	0.65	55.0	2.5	12.0	9.0	3200	same

Note: Levers vary R, D, E while holding macro/size near historical means – policy-relevant configurations in Kazakhstan.

Method: Scenario arithmetic using FE betas (D: **41.24** per unit; E: **0.34** per point) and descriptives (SD(D) = **0.09**; SD(E) = **8.32**). → $\Delta Y(D, \pm 1 \text{ SD}) = \pm 3.7116 \text{ bn}$; $\Delta Y(E, \pm 1 \text{ SD}) = \pm 2.8288 \text{ bn}$. *Baseline forecasts*: Scenario A path (**65.09**; **69.81**; **73.97** bn).

Table A7. Forecast sensitivity to ± 1 SD in D and E (2025–2027)

Year	Baseline (bn)	D + 1 SD	Δ vs base	D – 1 SD	Δ vs base	E + 1 SD	Δ vs base	E – 1 SD	Δ vs base
2025	65.09	68.8016	+3.7116	61.3784	-3.7116	67.9188	+2.8288	62.2612	-2.8288
2026	69.81	73.5216	+3.7116	66.0984	-3.7116	72.6388	+2.8288	66.9812	-2.8288
2027	73.97	77.6816	+3.7116	70.2584	-3.7116	76.7988	+2.8288	71.1412	-2.8288

Note: At realistic one-SD shifts, by 2027 + 1 SD in D adds ~ 3.71 bn, and + 1 SD in E adds ~ 2.83 bn to the baseline.

Associations between regulatory incentives and borrower ESG with green-loan volumes are stable across specifications, not driven by the largest banks, and specific to green lending (placebo). Oster bounds support resilience to plausible unobserved selection. Time-series diagnostics favor parsimonious ARIMAX with no residual autocorrelation. Scenario analysis shows coordinated improvements in R, D, E could materially lift volumes by 2027, but weak support risks stagnation. Given a short T, forecasts are illustrative and not intended as solvency predictions.