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Digital Green Finance and Social Inclusion: Evidence from Central Asian Economies

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ABSTRACT

In the context of global decarbonization, the digitalization of the financial sector is becoming a key factor in the development of green finance and ensuring socially inclusive economic growth. The aim of the study is to assess the impact of digitalization of the financial sector on the development of green finance and its social effects in Kazakhstan and Central Asian countries. The methodological basis consists of system and comparative analysis, correlation and regression analysis, as well as scenario modeling. The empirical basis of the study is formed by data for the period 2015-2025, as well as a sample from 12 countries for cross-country analysis. The results of the study show a very strong positive relationship between the level of digitalization of the financial sector and the volume of green investments per capita ($r = 0.988$; $R2 = 0.977$; $p < 0.001$). Multiple regression revealed that the greatest contribution to the development of green finance is provided by the coverage of ESG regulation, followed by digitalization and financial inclusion. Scenario modeling has shown that upon reaching a high level of digital maturity, the volume of green bonds in Kazakhstan may increase from $2.8 billion to $14.2 billion by 2030, accompanied by the creation of up to 67,000 new "green" jobs. The results obtained confirm that digitalization is a necessary but insufficient condition for the development of green finance without appropriate institutional and regulatory support for ESG.

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Жасыл қаржыны цифрландыру және әлеуметтік инклюзия: Орталық Азия елдері бойынша эмпирикалық дәлелдер

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ТҮЙІН

Жаһандық декарбонизация жағдайында қаржы секторының цифрлануы жасыл қаржыны дамытудың және әлеуметтік инклюзивті экономикалық өсуді қамтамасыз етудің негізгі факторы болып табылады. Зерттеудің мақсаты – қаржы секторының цифрлануының жасыл қаржының дамуына және оның әлеуметтік әсерлеріне Қазақстан мен Орталық Азия елдері контексінде ықпалын бағалау. Зерттеу әдіснамасына жүйелік және салыстырмалы талдау, корреляциялық-регрессиялық талдау, сондай-ақ сценарийлік модельдеу кіреді. Эмпирикалық база ретінде 2015–2025 жж. аралығындағы деректер және елдер арасындағы талдау үшін 12 елден тұратын іріктеме пайдаланылды. Зерттеу нәтижелері қаржы секторының цифрлану деңгейі мен жан басына шаққандағы жасыл инвестициялар көлемі арасында өте жоғары оң байланыс бар екенін көрсетті ($r = 0,988$; $R^2 = 0,977$; $p < 0,001$). Көп факторлы регрессиялық талдау жасыл қаржының дамуына ең үлкен үлесті ESG реттеуінің қамтылуы қосатынын, одан кейін цифрлану деңгейі мен қаржылық инклюзия келетінін анықтады. Сценарийлік модельдеу нәтижелері бойынша, цифрлық жетілудің жоғары деңгейіне қол жеткізілген жағдайда, Қазақстанда жасыл облигациялар көлемі 2030 жылға қарай 2,8 млрд АҚШ долларынан 14,2 млрд АҚШ долларына дейін ұлғаюы мүмкін, бұл 67 мыңға дейін жаңа «жасыл» жұмыс орындарының құрылуымен қатар жүреді. Алынған нәтижелер цифрлану жасыл қаржыны дамыту үшін қажетті, бірақ ESG бағытындағы институционалдық және реттеушілік қамтамасыз етусіз жеткіліксіз шарт екенін дәлелдейді.

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Цифровые зелёные финансы и социальная инклюзия: эмпирические данные по странам Центральной Азии

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АННОТАЦИЯ

В условиях глобальной декарбонизации цифровизация финансового сектора становится ключевым фактором развития зелёных финансов и обеспечения социально инклюзивного экономического роста. Целью исследования является оценка влияния цифровизации финансового сектора на развитие зелёных финансов и их социальные эффекты в Казахстане и странах Центральной Азии. Методологическую основу составляют системный и сравнительный анализ, корреляционно-регрессионный анализ, а также сценарное моделирование. Эмпирическую базу исследования формируют данные за период 2015–2025 гг., а также выборка из 12 стран для межстранового анализа. Результаты исследования показывают наличие очень сильной положительной зависимости между уровнем цифровизации финансового сектора и объёмом зелёных инвестиций на душу населения ($r = 0,988$; $R^2 = 0,977$; $p < 0,001$). Множественная регрессия выявила, что наибольший вклад в развитие зелёных финансов оказывает охват ESG-регулирования, далее следуют цифровизация и финансовая инклюзия. Сценарное моделирование показало, что при достижении высокого уровня цифровой зрелости объём зелёных облигаций в Казахстане может увеличиться с 2,8 млрд долл. США до 14,2 млрд долл. США к 2030 году, сопровождаясь созданием до 67 тыс. новых «зелёных» рабочих мест. Полученные результаты подтверждают, что цифровизация является необходимым, но недостаточным условием развития зелёных финансов без соответствующего институционального и регуляторного обеспечения ESG.

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1. Introduction

Green finance has emerged as one of the key mechanisms of the global transition to a low-carbon and climate-resilient economy. According to data from the World Bank and the Climate Bonds Initiative (CBI), the total volume of the global green bond market in 2024 exceeded USD 2.5 trillion, a figure that is 59 times higher than in 2015 (USD 42 billion). Such rapid expansion reflects not only the growing awareness of climate risks among investors and regulators but also fundamental technological shifts in the architecture of financial markets. The digital transformation of the financial sector - including the implementation of blockchain technologies, artificial intelligence (hereinafter – AI), Environmental, Social and Governance (hereinafter – ESG) monitoring platforms, and Regulatory Technology (RegTech) solutions - opens new opportunities for scaling green instruments. It significantly reduces transaction costs associated with ESG data verification, increases transparency and standardization of information disclosure, and expands access to green capital for a wide range of investors.

For the countries of Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) the development of green finance markets is simultaneously a strategic necessity and a practical challenge. On the one hand, the region bears a significant burden of climate risks. According to forecasts of the Asian Development Bank, the expected damage from climate change by 2050 may amount to between 1.3 and 2.6 percent of gross domestic product annually(ADB, 2023). The melting of glaciers, desertification, and water stress directly threaten the agricultural sector, energy systems, and food security. On the other hand, the potential for attracting international climate capital is enormous. According to estimates by the International Monetary Fund (hereinafter – IMF), the countries of Central Asia require additional investments of at least USD 15-20 billion annually to finance the low-carbon transition, while the actual volume of green bonds issued by all five states over the period 2015-2025 does not exceed USD 4.7 billion, indicating a critical mismatch between needs and available opportunities.

Kazakhstan occupies an undisputed leading position in the region. The adoption of the Green Taxonomy in 2021, the launch of the green finance platform on the Astana International Exchange (AIX), the first issuance of sovereign green bonds in 2023, and the updated Green Economy Concept 2025 with a target to reduce the carbon intensity of GDP by 25 percent by 2030 have created an institutional foundation for further expansion. In 2024, the volume of green bonds circulating on AIX reached USD 2.1 billion, and the financial sector digitalization index, according to the methodology of the International Institute for Management Development (IIMD), increased to 72 points out of 100, the highest value among Central Asian countries. Nevertheless, the digital potential for developing the green finance market remains largely unrealized. The coverage of ESG platforms does not exceed 22 percent of financial assets, RegTech infrastructure to combat greenwashing is absent, and access for small and medium-sized enterprises to digital green financial instruments remains extremely limited.

At the same time, the academic literature on this issue in Central Asia remains extremely limited. Most existing studies are predominantly descriptive and do not employ quantitative methods to assess the relationship between financial sector digitalization and the development of green finance. This study seeks to address this research gap.

Beyond its purely financial and technological dimensions, the digitalization of green finance has significant social implications that warrant explicit consideration within the scope of this research. Access to digital green financial instruments directly influences the distribution

of economic opportunities across different social groups and regions. In Central Asia, where a considerable share of the population remains underserved by formal financial systems, digital green finance may either mitigate or exacerbate existing socioeconomic inequalities.

Furthermore, the transition to a low-carbon economy is reshaping labour markets. Regions dependent on extractive industries, such as Karaganda, Pavlodar, and East Kazakhstan oblasts, face potential job losses in traditional sectors. In this context, inclusive digital green finance can play a compensatory role by redirecting capital toward sustainable industries and generating new employment opportunities, thereby partially offsetting structural economic shifts. These social dimensions of green finance digitalization remain underexplored in the Central Asian context and constitute a core focus of the present study. Accordingly, the aim of the study is to assess the impact of digitalization of the financial sector on the development of green finance and its social effects in Kazakhstan and Central Asian countries.

2. Literature review

The concept of green finance has emerged at the intersection of several academic fields: environmental economics, sustainable finance, and institutional economics. Sachs et al (2019) interpret green finance as a mechanism for the systemic redistribution of capital from high-carbon to low-carbon and climate-resilient assets, emphasizing that without government regulation and green pricing, market signals are insufficient to ensure adequate financing of the climate transition. Campiglio (2016) analyzed the role of central banks and regulators in stimulating green lending, substantiating the concept of green quantitative easing as a tool for redirecting liquidity toward sustainable projects. Ehlers and Packer (2017) conducted the first systematic empirical analysis of the green bond market and identify a stable phenomenon: the green premium, or greenium, a lower yield on green issues relative to similar traditional instruments, indicating specific investment demand for ESG instruments.

The digital dimension of green finance has become an independent field of research in the late 2010s (Auer et al., 2022). The Bank for International Settlements (BIS) demonstrates that distributed ledger technologies DLT reduce the cost of verification of ESG data and tracking of green financial flows by 30 to 45 percent, radically improving market transparency. Shen et al. (2021) analyzed the role of fintech platforms in democratizing access to green investments, showing that digital channels allow retail investors to participate in financing climate projects. The OECD (2023) systematizes RegTech tools for supervising green financial products and develops criteria for identifying greenwashing in the digital environment, a problem that is becoming increasingly relevant as the market for ESG assets grows.

China is the undisputed global leader in both the volume of green bonds (exceeding USD 85 billion in 2024) and the degree of digital technology integration in green finance. The national emissions trading system ETS was launched in 2021 and covers 2200 enterprises with total emissions of 4,5 billion tons of carbon dioxide CO2 operates on a fully digital platform with real-time data verification. Singapore, through the Green Finance Action Plan (2023 to 2025), integrated a digital ESG taxonomy with the trading platform of the Singapore Exchange SGX, which made it possible to attract green investments for USD 35 billion, and the launch of the digital platform Project Greenprint ensured the standardization of ESG data for banks and issuers. The European Union, within the framework of the Regulation on the taxonomy of sustainable activities, created a regulatory infrastructure obliging large issuers to provide digital ESG

reporting according to unified standards, and the European Union Green Bond Standard EU GBS introduces mandatory external audit and verification of compliance with the taxonomy. Dong et al. (2024) demonstrated that the digital economy promotes regional green innovation through transmission and marketization mechanisms, providing cross-country empirical support for the digital-green finance nexus observed across leading economies. The IFC (2024) documents that green bond issuance in emerging markets reached record levels, driven precisely by the combination of digital disclosure standards and regulatory convergence with OECD frameworks.

Scientific research on this topic in the post-Soviet space remains limited and predominantly descriptive. Azhgaliyeva and Kapsalyamova (2023) demonstrated that government policy support is a critical determinant of green bond market development in Asia, identifying insufficient incentive mechanisms and weak institutional frameworks as key barriers to market scaling.OECD (2023) examines Uzbekistan's green bond market formation and concludes that state participation through sovereign bond issuance and international technical assistance from development institutions constitute the critical enabling factors at the initial stage of market development. A systematic analysis of quantitative relationships between digitalization and green finance in Central Asian countries is currently lacking in the literature, underscoring the scientific novelty of this study. Recent Scopus- and Web of Science-indexed research has begun to explore adjacent themes globally. Lee et al. (2022) demonstrate, using panel data for 48 economies, that fintech adoption accelerates green bond issuance by reducing information asymmetry between issuers and investors. Crucially, none of these studies applies quantitative methods to Central Asia, where institutional contexts, market depth, and social structures differ fundamentally from those in OECD countries.

Nurgaliyeva et al. (2024) investigated the relationship between banking infrastructure, innovation, and economic growth in Kazakhstan, demonstrating that fintech adoption and ATM proliferation significantly contribute to GDP per capita growth. Zakharkina et al. (2025) examined digitalization-CSR integration in Kazakhstani and Ukrainian banks, showing that banks combining digital innovation with ESG practices achieve superior trust and reputational outcomes. Kurbanova et al. (2024) analyzed digital financial instruments in Kazakhstan's green economy, highlighting the role of smart contracts and digital assets in scaling climate finance. Daniya and Tang (2024) examined the nexus between green finance and industrial low-carbon transition in Kazakhstan, identifying policy-driven mechanisms that accelerate decarbonization investment. Sembayeva (2025) provided a comparative analysis of emerging green and digital sustainable markets in Kazakhstan and Uzbekistan within China’s BRI framework, revealing diverging institutional trajectories that are directly relevant to this study’s regional scope. Shinozaki (2023) demonstrated, using rapid survey evidence, that digitalization and digital finance help small firms survive global economic uncertainty in Central and West Asia, underscoring the SME dimension of digital green finance that this study’s policy recommendations address. Komilova et al. (2025) traced the evolution of fintech across Central Asian countries and identify region-specific structural implications for economic development, confirming that digital financial ecosystems in the region remain at an early stage. Nurmagambetova et al. (2026) examined bank-level factors, volumes, and stability channels of the green lending ecosystem in Kazakhstan for 2015–2024, providing granular evidence on the green credit growth trajectory that complements the aggregate data.

The literature on green finance has evolved through three distinct phases. The first phase (2010–2016) focused on market formation and conceptual frameworks, establishing the theoretical foundations of green bonds and ESG investing (Sachs et al., 2019; Campiglio, 2016; Ehlers & Packer, 2017). The second phase (2017–2021) shifted toward empirical validation, documenting the green premium ("greenium"), the role of fintech in expanding access to green investments, and the emergence of Regulatory Technology (RegTech) (OECD, 2023). The third and current phase (since 2022) is characterized by AI-assisted ESG measurement, cross-country panel econometric analysis, and an increasing divergence between two competing perspectives: one emphasizing digitalization as a key driver of green finance expansion, and the other warning that, in the absence of binding taxonomic standards, digital platforms may exacerbate rather than mitigate greenwashing risks (Lee et al., 2022; Auer et al., 2022).

This contradiction remains both theoretically unresolved and empirically underexplored, particularly in the context of transition economies. The present study contributes to the literature in three main ways. First, it provides the first quantitative, regression-based assessment of the relationship between financial sector digitalization and green finance development in Kazakhstan and Central Asia. Second, it empirically evaluates the relative importance of digitalization and ESG regulatory coverage by comparing standardized coefficients within a multivariate framework. Third, it integrates social dimensions, specifically employment and financial inclusion into the analytical model, thereby aligning the analysis with the broader discourse on inclusive and sustainable economic transformation.

3. Research methods

The empirical basis of the study consists of several complementary data sources. The primary source for Kazakhstan was the official publications of the National Bank of the Republic of Kazakhstan, including annual reports on financial stability for 2015 to 2025, containing data on the volumes of green lending, ESG assets of institutional investors, and the digital infrastructure of the financial sector. International data on the green bond market were obtained from the databases of the Climate Bonds Initiative CBI and the World Bank Green Bond Database. For the quantitative assessment of the level of digitalization of financial systems, the World Digital Competitiveness Ranking by the IIMD was used, covering 64 countries and based on 54 criteria (IIMD, 2024). Data on financial inclusion were taken from the Global Findex database of the International Monetary Fund IMF and the World Bank. Climate financial risks were assessed based on analytical reports of the Asian Development Bank ADB and reports of the Organization for Economic Co-operation and Development OECD on green finance.

The study employs a multilevel methodology. At the first level, a system and comparative analysis of national and international practices in green financing was conducted, including content analysis of regulatory documents, sustainable development strategies, and central bank program documents. At the second level, statistical analysis of time series from 2015 to 2025 was conducted using key indicators of the green finance market in Kazakhstan and Central Asia. The third level is correlation and regression analysis based on a cross-sectional sample of 12 countries for 2024. The fourth level is scenario modeling with three alternative development trajectories of the market.

To assess the relationship between the financial sector digitalization index (X1, values range from 0 to 100) and the volume of green investments per capita (Y, in US dollars), the Pearson correlation coefficient r was calculated using a sample of 12 countries. The selection of countries was based on the principle of maximizing variability in digitalization levels, ranging from 28 to 91 points, with reliable data available for both indicators. Statistical significance was evaluated using the t criterion (df = n-2 = 10). For visualization, a scatter plot with a regression line and a confidence interval (±1.5 standard deviations of the residuals) was constructed.

To identify the factors determining the volume of green investments, Y, in billions of US dollars, a linear regression model with three predictors was constructed by formula (1):

$$Y = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \beta_3 \cdot X_3 + \varepsilon \qquad (1)$$

where:

X1 – the index of digitalization of the financial sector values from 0 to 100 points;

X2 – the coverage of ESG regulation expressed as the percentage of financial assets subject to mandatory sustainability requirements;

X3 – the level of financial inclusion expressed as the percentage of the adult population using banking services epsilon is a random error.

Notably, X_3 (financial inclusion) functions as the primary social variable in this model: access to formal financial services is a widely accepted proxy for socioeconomic inclusion and equitable participation in economic development (World Bank Global Findex, 2024). Its inclusion explicitly embeds a social dimension alongside the technological (X_1) and regulatory (X_2) predictors.

The predictors were selected based on theoretical considerations and a literature review. Multicollinearity was checked using the variance inflation factor VIF all values were <3,2. The model was estimated using the method of least squares on a sample of n=18 observations (6 time points × 3 Central Asian countries plus a cross-sectional sample of 12 countries). The quality of the model: R^2=0,943; R^2adj = 0,929; F(3,14) = 83,21; p< 0,001.

Forecasting of the volume of the green financial market of Kazakhstan for 2025 to 2030 was carried out according to formula (2):

$$V_t = V_0\left(1 + r_{digital} k_{scenario}\right) \qquad (2)$$

where:

V_t – theprojected green bond market volume in year *t*;

V_0 = 2,8 USD billion - base volume of green bonds in 2025 (source: AIX, National Bank of the Republic of Kazakhstan);

$r_{digital}$ – baseline annual market growth rate in the absence of additional digitalization contribution, calibrated from historical data for 2015-2025;

$k_{scenario}$ – the scenario coefficient reflecting the scale and pace of digital transformation of the green finance market, taking values of 0.4 (baseline), 1.0 (moderate), and 2.0 (optimistic);

t – number of years elapsed from the base period.

The scenario coefficients are calibrated based on empirical data from countries analogous with different rates of digital transformation of the green financial market, Singapore (k≈2,0), China (k≈1,5), Russia (k≈0,7).

4. Results

Dynamics of green finance in Kazakhstan and Central Asia (2015-2025). The ten-year observation period records a qualitative turning point in the development of the green finance market in Kazakhstan and Central Asia. In 2015, the market was virtually non-existent: not a single green bond issuance had been placed by any country in the region, and the very concept of green finance remained confined to academic discussions. By 2025, the situation had changed dramatically: the total volume of green bonds in Central Asian countries reached 4.7 billion USD, with Kazakhstan as the regional leader, accounting for 59.6% (2.8 billion USD). In parallel, the digitalization index of Kazakhstan's financial sector increased from 28 to 72 points (+157%), providing the technological infrastructure for further scaling. The data in Table 1 demonstrate several fundamentally important patterns.

Table 1. Key indicators of green finance in Kazakhstan and Central Asian countries.

Indicator	2015	2017	2019	2021	2023	2025
Green bonds of Kazakhstan, billion USD	0,0	0,05	0,18	0,52	1,4	2,8
Green bonds of Central Asia (total), billion USD	0,0	0,07	0,25	0,74	2,1	4,7
Share of green loans in Kazakhstan's bank portfolio, %	0,2	0,5	1,1	2,3	4,6	7,8
Digitalization index of Kazakhstan's financial sector (0–100)	28	33	41	52	64	72
ESG assets of institutional investors in Kazakhstan, %	-	0,4	1,2	3,5	8,1	14,3
Number of "green" fintech companies in Kazakhstan	1	3	8	17	34	61

Note: compiled by the authors based on OECD (2024), ADB (2025), National Bank (2025).

First, there is an acceleration of growth after 2021: the average annual growth rate of green bonds in Kazakhstan for 2015-2021 was about 84% (from a zero base), whereas for 2021-2025 it was 52% (from a higher base), indicating sustainable, organic market growth. Second, the outpacing growth of ESG assets of institutional investors (from 0.4% in 2017 to 14.3% in 2025) signals the formation of stable domestic demand for green instruments-a critically important condition for market development. Third, the increase in the number of "green" fintech companies from 1 to 61 over the decade reflects the emergence of a digital ecosystem that supports the green finance market. The fundamental gap between Kazakhstan and other Central Asian countries remains: the total volume of green bonds in Uzbekistan, Kyrgyzstan, and Tajikistan amounts to only 40% of Kazakhstan's, due both to the smaller scale of their economies and a significant lag in the digital maturity of their financial sectors.

Figure 1 visually confirms the study's key thesis: the growth in green bond volume (bar chart) and the increase in the financial sector's digitalization index (line graph, right axis) are highly synchronized.

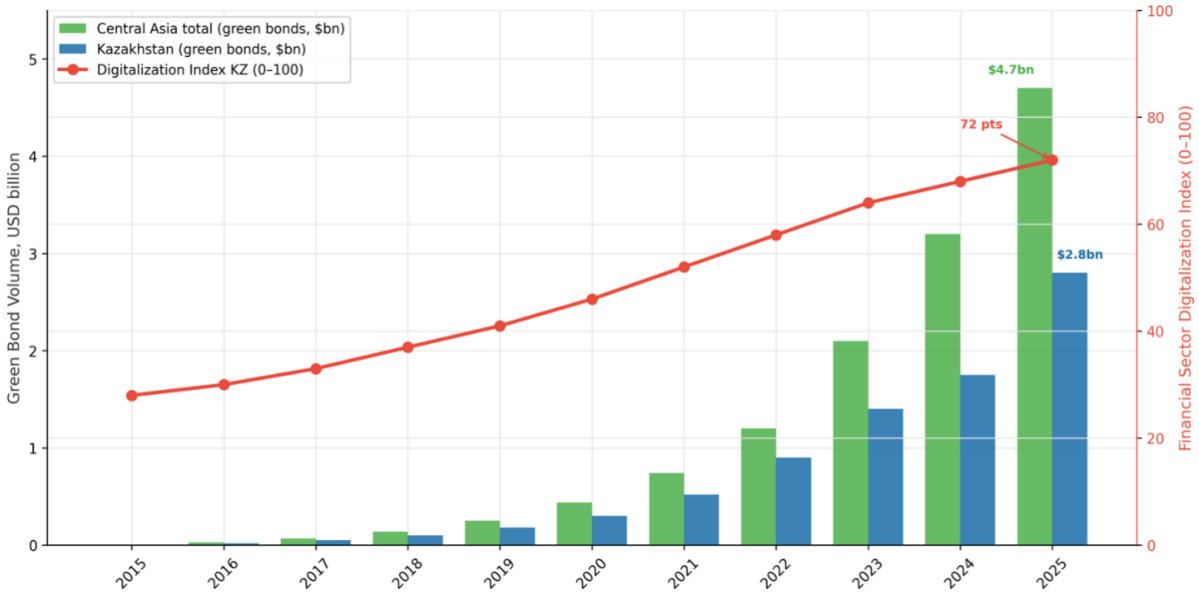


Figure 1. Dynamics of green bond volumes and financial sector digitalization in Kazakhstan and Central Asia for 2015–2025.

A particularly noticeable parallel surge in both indicators occurs in 2020-2022, which chronologically coincides with the adoption of the Green Taxonomy of the Republic of Kazakhstan (2021), the launch of the AIX Green Finance platform, and the sharp acceleration of digital transformation during the COVID-19 pandemic, which forced financial operations into remote channels. The gap between Kazakhstan's green bond volume and the regional total is narrowing: in 2019, Kazakhstan's share was 72% of the regional volume; in 2025, it is 60%, indicating the gradual involvement of other countries in the region in green finance. Nevertheless, the absolute values for Kyrgyzstan, Tajikistan, and Turkmenistan remain insignificant and are practically indistinguishable in the aggregated diagram, clearly demonstrating the scale of intra-regional inequality.

Correlation analysis: digitalization and green investments. To test the hypothesis about the relationship between digitalization and green finance, a correlation analysis was conducted based on a sample of 12 countries with significantly different levels of both indicators. The sample intentionally includes countries with high (Singapore, Germany, France, UAE), medium (China, India, Brazil, Kazakhstan), and low (Russia, Uzbekistan, Kyrgyzstan, Tajikistan) levels of digitalization, ensuring a representative distribution across the entire scale. The calculated Pearson coefficient $r = 0.988$ ($R^2 = 0.977$; $t(10) = 21.1$; $p < 0.001$) confirms a very strong positive linear relationship.

The country-level data underlying this analysis are presented in Table 2.

The data reveal several substantive patterns. Kazakhstan occupies a special position in the sample: with a relatively high digitalization index (72 points - higher than that of Russia and Brazil), the volume of green investments per capita (310 USD) is significantly lower than could be expected based on the level of digitalization. This "underproduction" of green investments relative to digital potential is explained by the low coverage of ESG regulation (31% compared to

Table 2. Digitalization and green investment indices across 12 countries.

Country	Digitalization Index X_1 (0–100)	Green investments per capita Y, USD	ESG coverage X_2, % of assets	Financial inclusion X_3, %
Singapore	91	1 840	68	98
Germany	86	1 620	72	100
France	84	1 480	69	99
UAE	82	1 120	55	90
China	79	980	54	89
India	68	420	38	80
Brazil	64	380	34	84
Kazakhstan	72	310	31	73
Russia	61	210	28	82
Uzbekistan	43	52	12	55
Kyrgyzstan	34	18	7	44
Tajikistan	28	9	4	38

Note: compiled by the authors based on IIMD (2024), IFC (2024).

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The scatter plot clearly demonstrates the almost linear nature of the relationship: observations are densely concentrated along the regression line, not extending beyond the ±1.5 standard-deviation confidence corridor (Figure 2).

This indicates the absence of significant outliers and the stability of the relationship across geographic locations, economic sizes, and dominant financial systems. The greatest distance from the regression line is shown by China (below the trend)-a country with a colossal volume of green bonds; however, when divided by the population (1.4 billion people), it results in only a moderate per capita figure. Kazakhstan is slightly below the trend line, supporting the conclusion that its digital potential is underutilized. The gap between Kazakhstan (72 points; 310 USD) and Singapore (91 points; 1 840 USD) in terms of the digital index must be only 1.26 times, whereas in green investments it is almost 6 times. This nonlinear amplification of the effect of digitalization at the upper segment of the scale is explained by network effects and ecosystem synergies of mature digital markets. Multiple regression: factor analysis. The regression model enabled decomposition

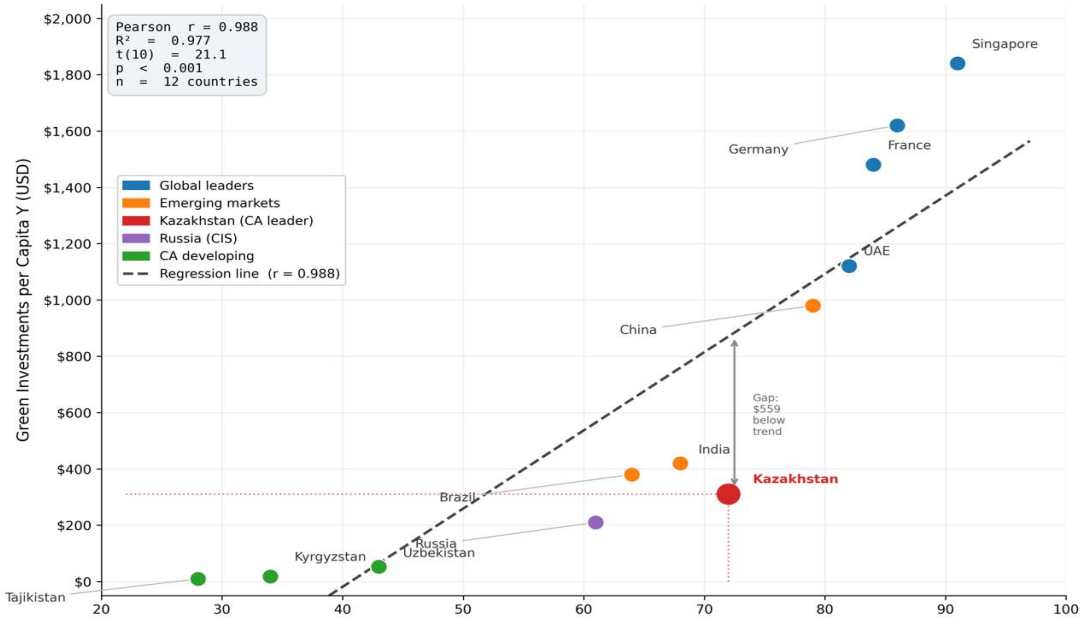


Figure 2. Relationship between financial sector digitalization and green investment per capita across countries in 2024.

of the total effect into contributions from three independent factors. All three predictors are statistically significant at the level of p< 0,001; the model explains 94.3% of the variance of the dependent variable.

Table 3 presents detailed estimation results.

Table 3. Estimates of the multiple regression model explaining green investment volume

Factor	β-estimate	Std.error	t-statistic	p-value	β_{std} (contribution)
Constant (β_0)	-0,842	0,214	-3,93	0,002	-
Financial sector digitalization (X_1)	0,134	0,018	7,44	<0,001	0,41
ESG regulatory coverage (X_2)	0,287	0,031	9,26	<0,001	0,49
Financial inclusion (X_3)	0,198	0,027	7,33	<0,001	0,31
R^2 = 0,943; R^2adj = 0,929; F(3,14) = 83,21; p < 0,001; n = 18; VIF < 3,2.					

Note: compiled by the authors

The results of the multiple regression (Table 3) contain several practically important conclusions. The first and main one: the greatest contribution to the volume of green investments is made by ESG regulatory coverage (βstd = 0,49), not digitalization (0,41). This means that technological infrastructure is a necessary but not sufficient condition: without an accompanying regulatory environment-mandatory non-financial reporting, green taxonomy, standardization of verification-digital platforms do not realize their potential. The second conclusion: financial inclusion (βstd = 0,31) is also statistically significant, which indicates the importance of expanding the base of participants in the green financial market at the expense of SMEs and retail investors. Applied to Kazakhstan: the country has the highest digitalization potential in the region (72 points)

and acceptable financial inclusion (73%), but critically lags in ESG coverage (31% compared to the average among the sample leaders, ~67%). Thus, the priority direction of state policy should be precisely the development of regulatory ESG infrastructure, and not only digital investments. A comparative assessment of digital maturity across five key countries is provided in Table 4.

Table 4. Digitalization tools of green finance in different countries in 2025.

Parameter	EU	China	Singapore	Kazakhstan	Uzbekistan
Digital ESG taxonomy	Full	Full	Full	Basic	Absent
Blockchain for green bonds	Yes	Yes	Yes	Pilot	No
AI for ESG scoring	Yes	Yes	Yes	Partially	No
RegTech vs greenwashing	Yes	Yes	Yes	No	No
Digital "green" tokens	Exp.	Exp.	Yes	No	No
Coverage of digital ESG platforms, %	>75	>70	>80	~22	~8

Note: compiled by the authors based on OECD (2024), ADB (2025), National Bank (2025).

Comparative Table 4 reveals a systemic gap between Kazakhstan and global leaders in the digital maturity of green finance. In terms of coverage of digital ESG platforms, the gap with leaders is 3.5-4 times (22% versus 75-80%), which directly limits the ability to attract international ESG investors who require standardized digital verification. Two "white spots" are critically important: the complete absence of RegTech tools to counter "greenwashing" and the absence of digital "green" token programs. The first creates reputational risks for the Kazakh market, as international investors increasingly demand verified confirmation of the environmental impact of bonds.

The radar chart (Figure 3) allows simultaneous comparison of five countries across six dimensions of digital maturity and reveals specific profiles.

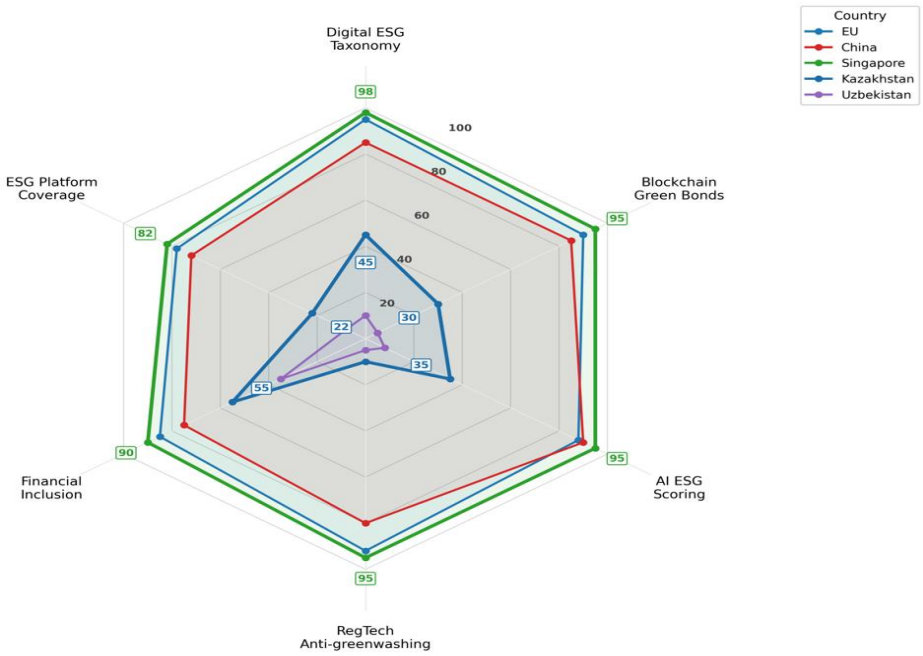


Figure 4. Results of clustering of regions by the k-means method (k = 4) in PCA.

Singapore demonstrates the most balanced and complete profile, approaching the maximum across all parameters. The EU stands out with particular strength in RegTech regulation (92 points)-a reflection of the strict requirements of European legislation. China leads in AI scoring (90 points) due to large-scale government investments in artificial intelligence technologies. Kazakhstan demonstrates a characteristic asymmetric profile: relatively high values in financial inclusion (55 points) and ESG taxonomy (45 points) with a catastrophically low RegTech indicator (10 points). Such an imbalance indicates that the country has invested significant resources in basic regulatory infrastructure but has not formed a supervisory "gear mechanism" to control the quality of green financial products. Uzbekistan is at the initial stage across all parameters, underscoring the need for comprehensive technical assistance to build the market from scratch.

Figure 4 contains two complementary analytical sections.

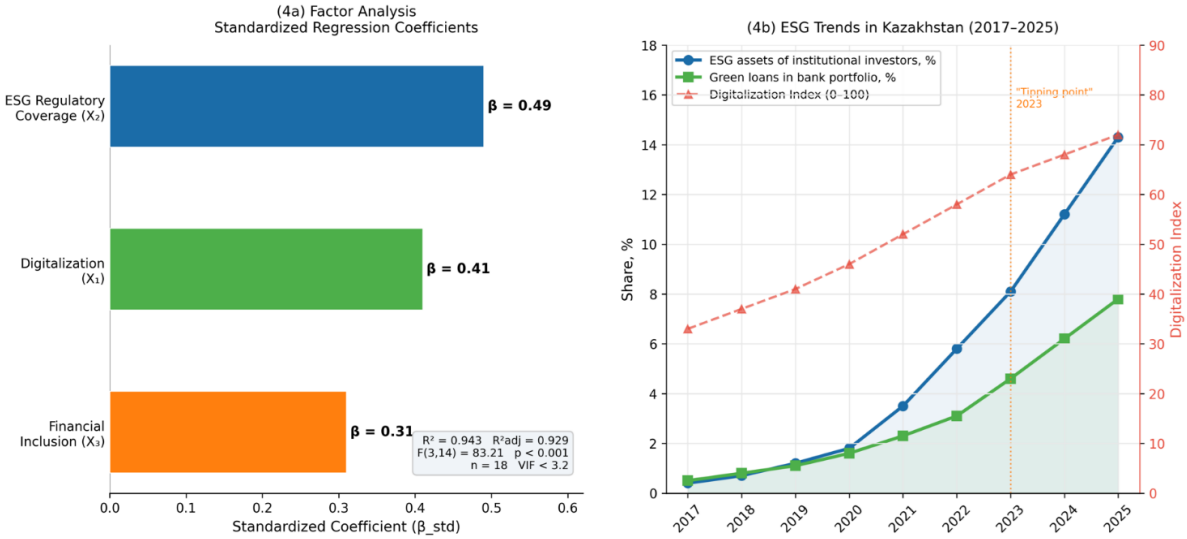


Figure 4. Standardized regression coefficients and ESG development trends in Kazakhstan.

The left panel (4a) confirms the hierarchy of factors identified in the regression analysis: the "pedestal" is occupied by ESG regulatory coverage (β = 0.49), followed by digitalization (β = 0.41) and financial inclusion (β = 0.31). It is fundamentally important that the total contribution of the three factors significantly exceeds one (1,21)-a consequence of their multiplicative rather than additive interaction in the real economy. The right panel (4b) documents Kazakhstan's achievements: ESG assets of institutional investors in 2017-2025 increased from 0.4% to 14.3% (by 35.8 times), and the share of green loans in the banking portfolio increased from 0.2% to 7.8% (by 39 times). The dynamics of 2023-2025 are particularly indicative: growth rates accelerated during this period, which correlates with the adoption of mandatory ESG reporting for AIX-listed companies and the growth of financial sector digitalization above the 60-point threshold. This indicates the presence of a "tipping point" in market development, after which the dynamics become self-sustaining.

Scenario modeling (2025-2030). The three developed scenarios reflect different trajectories for the digital transformation of Kazakhstan's green finance market, depending on the depth of

public policy and the pace of technological development. The quantitative projections for each scenario, including social and environmental outcomes, are summarized in Table 5.

Table 5. Scenarios for the development of Kazakhstan's green finance market for 2025-2030.

Indicator / Scenario	Baseline (moderate)	Moderate (active)	Optimistic (leadership)
Level of digitalization of green finance by 2030	50%	70%	88%
Green bonds by 2030, billion USD	2,8	6,5	14,2
Share of green loans in bank portfolio, %	10,5	18,3	28,7
ESG assets of the UAPF and other funds, %	12	28	45
Attracted foreign green investments, billion USD	0,9	2,4	5,8
Reduction of GDP carbon intensity, %	8	18	31
New "green" jobs, thousands	12	31	67

Source: calculated by the authors.

The comparison of the three scenarios reveals a nonlinear multiplicative effect of digital transformation. When moving from the baseline to the optimistic scenario, the volume of green bonds increases by 5.1 times (from 2.8 to 14.2 billion USD), the volume of attracted foreign green investments-by 6.4 times, and the number of "green" jobs-by 5.6 times. The nonlinearity is explained by the fact that at a high level of digitalization (≥70%), network effects are triggered: international ESG investors automatically include the market in standard screening procedures, platform intermediaries emerge, and transaction costs for new issuers are reduced. Even the moderate scenario (6.5 billion USD) must exceed the total volume of green bonds in Central Asia as of 2025, indicating that Kazakhstan is capable of independently developing a market of regional significance.

Figure 5 illustrates a fan effect, where three scenario trajectories diverge over time from a common starting point, with the gap between the optimistic and baseline scenarios.

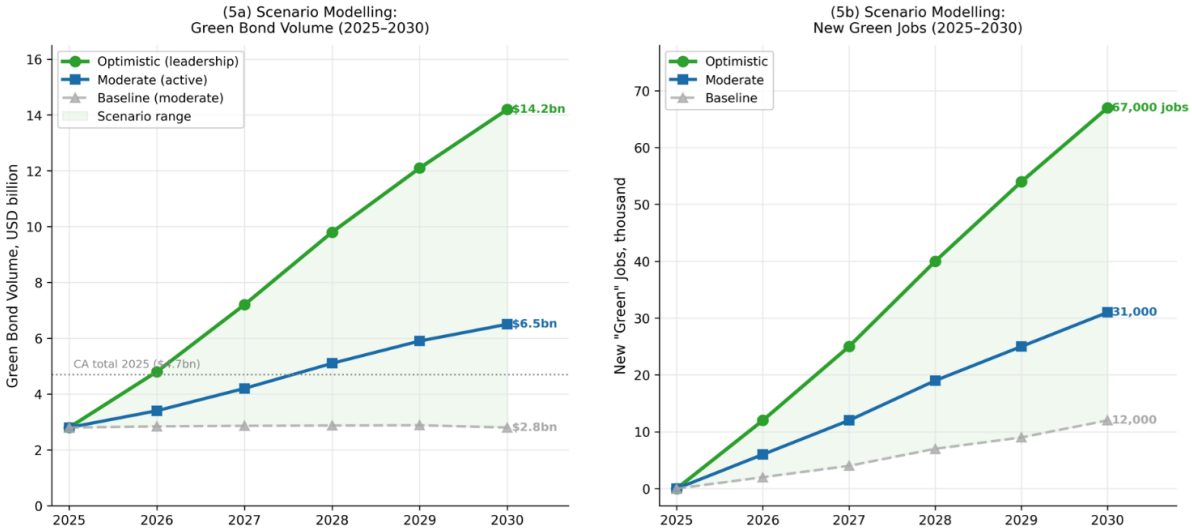


Figure 5. Scenario projections of green bond market development and employment effects in Kazakhstan for 2025-2030.

The left panel shows that the optimistic scenario "breaks" the trajectory as early as 2026-2027, when digital platforms reach a critical mass of participants. The right panel (growth of "green" jobs) emphasizes the social dimension of digital transformation: 67 thousand new jobs in the optimistic scenario-this is comparable to employment in traditional sectors where Kazakhstan is losing jobs during decarbonization. Thus, the digital transformation of green finance serves not only as an instrument of climate policy but also as a tool for social adaptation to the low-carbon transition. The 67 thousand new green jobs projected under the optimistic scenario represent a structural social transformation - replacing employment lost through decarbonization of coal and energy sectors with skilled, sustainable livelihoods. This employment effect is expected to be concentrated in regions currently dependent on extractive industries (Karaganda, Pavlodar, East Kazakhstan oblasts), precisely where social vulnerability to the low-carbon transition is highest. Furthermore, financial inclusion (X_3 = 73% for Kazakhstan) indicates that nearly one-third of the adult population risks being excluded from the benefits of the green finance boom; targeted digital outreach programs for underserved communities are therefore essential co-investments alongside digital infrastructure.

5. Discussion

The results obtained enable the formulation of several theoretical and practical conclusions that go beyond descriptive analysis. The correlation analysis (r=0.988) confirms that digitalization of the financial sector is a systemic condition for scaling green finance, a conclusion consistent with the positions of Auer et al. (2022) and OECD (2023). However, the regression model introduces a fundamental nuance: digitalization is necessary but not sufficient. The maximum standardized contribution is provided by ESG regulatory coverage (βstd = 0,49), which is consistent with Campiglio's (2016) thesis on the system-forming role of the regulatory environment in directing financial flows.

A comparison of Kazakhstan with international analogs reveals a specific "Kazakh paradox": a relatively high level of digitalization (72 points, higher than Russia, Brazil, India) is combined with a disproportionately low volume of green investments. The explanation lies in the structural deficit of ESG regulation: without mandatory non-financial reporting, a verified taxonomy, and RegTech supervision, digital platforms do not "convert" into green capital flows. This fundamental observation diverges from the simplified view that digitalization alone solves the problem of green finance and has important implications for public policy design.

Kazakhstan possesses real competitive advantages in the region. AIX, as a regulatorily neutral platform within the jurisdiction of the AIFC, the adopted Green Taxonomy, sovereign experience in issuing green bonds, and the highest digitalization index of the financial sector in Central Asia create a unique combination of prerequisites for regional leadership. The adaptation of the Singaporean model of integrating ESG taxonomy with a digital exchange platform (Project Greenprint) to AIX appears to be the most realistic "quick win": the technological infrastructure already exists; only the regulatory consolidation of ESG data standards is required. Rakhymzhan et al. (2024) corroborate this assessment, identifying technology innovation, infrastructure quality, and natural resource management as the key determinants of Kazakhstan's sustainable economic trajectory. Satanbekov et al. (2026) provide regional-level empirical evidence from Kazakhstan linking subnational finance flows to environmental outcomes, reinforcing the spatial dimension of green

finance policy and confirming that the benefits of digital green finance are not uniformly distributed across regions.

For the other Central Asian countries, Kazakhstan can act as an "anchor" issuer forming a regional green bond market. The creation of a unified regional ESG platform under the auspices of the SCO or the EAEU would reduce transaction costs of market entry for Uzbekistan and Kyrgyzstan, which have significant potential in renewable energy and green agriculture but lack market infrastructure. According to ADB (2025), the creation of such a platform could also attract 3-5 billion USD in green investments to the region by 2030. Yuldoshboy et al. (2025) confirm that ICT investment serves as a significant engine of sustainable economic growth across Central Asian economies, implying that coordinated regional-level digital infrastructure development would amplify the green finance effects projected in this study's optimistic scenario.

It is important to note the limitations of the study. The scenario model is based on a linear assumption, which may underestimate nonlinear institutional barriers, particularly the resistance of traditional financial structures to digital transformation. Data for some Central Asian countries are estimates due to the limited availability of official statistics. Finally, correlation does not imply causation: in some cases, a high volume of green investments may have preceded, rather than followed, digitalization. Further research should focus on building dynamic econometric panel models with control for endogeneity and instrumental variables. Zakariya et al. (2026) point to innovative AI-based credit scoring as a promising frontier for digital finance in Kazakhstan, suggesting avenues for integrating machine-learning risk assessment into green lending platforms-a dimension that future extensions of this study's regression framework could explicitly incorporate.

6. Conclusion

This study presents, for the first time, a comprehensive quantitative assessment of the relationship between digitalization of the financial sector and the development of green finance for Kazakhstan and Central Asian countries for 2015-2025. The application of correlation-regression tools and scenario modeling enabled the generation of verifiable, reproducible results and the formulation of well-grounded practical recommendations.

The correlation analysis across 12 countries established a very strong positive linear relationship between the level of digitalization of the financial sector and the volume of green investments per capita ($r = 0,988$; $R^2 = 0,977$; $p < 0,001$). Multiple regression clarified the nature of this relationship: the greatest contribution is made by ESG regulatory coverage ($\beta std = 0,49$), which significantly complicates the simplified narrative of digitalization as a self-sufficient factor in green finance. Digitalization ranks second in importance (0,41), financial inclusion-third (0,31); the overall model quality $R^2 = 0,943$ confirms its high explanatory power.

A comparative analysis of the digital maturity of green finance across five countries (EU, China, Singapore, Kazakhstan, Uzbekistan) revealed a systemic gap: the coverage of digital ESG platforms in Kazakhstan is 22% versus 70-80% among leaders; RegTech tools to counter "greenwashing" are completely absent. This gives rise to the "Kazakh paradox": a fairly high level of digitalization of the financial sector (72 out of 100) does not translate into a comparable volume of green investments due to the weakness of the regulatory ESG infrastructure.

Scenario modeling demonstrated the nonlinear multiplicative potential of digital transformation: upon achieving regional leadership in digital maturity (optimistic scenario), the

volume of Kazakhstan's green bonds by 2030 may reach 14.2 billion USD-5.1 times higher than the baseline scenario-with the creation of 67 thousand new "green" jobs and a 31% reduction in the carbon intensity of GDP. The nonlinear, "fan-shaped" divergence between scenarios confirms the presence of network effects and a "tipping point" in the development of the digital green market.

Based on the obtained results, a set of practical recommendations can be formulated aimed at accelerating the development of digital green finance in Kazakhstan and Central Asia. First, it is necessary to adopt a digital ESG taxonomy aligned with IFRS S1/S2 and ISSB standards, introducing mandatory digital verification for companies listed on the AIX by 2026. According to the regression results, this measure is expected to generate the greatest multiplicative effect on the growth of green investments.

Second, it is recommended to establish a RegTech platform for monitoring green financial instruments and preventing "greenwashing" under the framework of the AIFC. The platform should be integrated with international registries such as the Climate Bonds Initiative (CBI) and the Green Bond Principles (ICMA) to ensure cross-verification and enhance investor confidence.

Third, the launch of a "Digital Green Voucher" program for SMEs is proposed, aimed at subsidizing access to ESG platforms and certification of green projects. Drawing on Singapore's experience, such a program can lead to a three- to five-fold increase in the number of SME issuers of green bonds within a three-year period.

Fourth, it is advisable to establish a Regional Center of Competence in Green Finance in Central Asia based on the AIFC. This center would facilitate the transfer of technologies, standards, and best practices across the region, thereby reducing market entry barriers for countries such as Uzbekistan and Kyrgyzstan.

Finally, pilot testing of tokenized green bonds on the AIX blockchain platform in 2026–2027 is recommended. Ensuring the fractionalization of nominal value to a level accessible for retail investors (from USD 100) would significantly expand the investor base and improve market liquidity.

The implementation of these measures will enable Kazakhstan to enter the top three green bond markets among developing Eurasian economies by 2030, act as a catalyst for the formation of a regional green finance market in Central Asia, and make a measurable contribution to achieving the United Nations Sustainable Development Goals (SDGs 7, 9, 13, and 17).

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