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GREEN BOND MARKET: GLOBAL TRENDS AND DEVELOPMENT FACTORS

The methodology is based on a multi-dimensional approach that combines institutional and comparative analysis of secondary data from international organizations such as the Climate Bonds Initiative, the World Bank, and the OECD. The study applies an analytical framework founded on a scenario-based approach and the logic of machine learning algorithms, including LSTM and Transformer architectures, to analyze market dynamics under conditions of data scarcity. The results reveal that green bonds represent approximately 60 percent of the global sustainable debt market, with growth driven by regulatory standardization and institutional investor demand. However, a significant structural gap remains between developed and emerging markets. The Kazakhstani market is identified as being in its early stages of development, where the Astana International Financial Centre acts as the primary institutional driver through regulatory incentives and certification infrastructure. The scientific novelty of the research lies in the development of an integrated analytical framework that combines ESG institutional indicators and macroeconomic factors with predictive machine learning logic. This approach establishes a theoretical basis for utilizing deep learning to capture non-linear dependencies in emerging green finance ecosystems where traditional econometric models show limited efficiency.

Keywords: *green bonds; sustainable finance, ESG investing, climate finance, financial markets, institutional investors, regulatory framework, green economy, machine learning.*
Кілт сөздер: *жасыл облигациялар, тұрақты қаржыландыру, ESG-инвестициялар, климаттық қаржыландыру, қаржы нарықтары, институционалдық инвесторлар, нормативтік реттеу, жасыл экономика, машиналық оқыту.*
Ключевые слова: *зелёные облигации, устойчивое финансирование, ESG-инвестирование, климатическое финансирование, финансовые рынки, институциональные инвесторы, нормативное регулирование, зелёная экономика, машинное обучение.*

Introduction. In the context of accelerating climate change and the transformation of the global financial system, sustainable finance instruments are gaining increasing importance. Among them, green bonds play a key role in mobilizing capital for environmentally sustainable projects and supporting the transition toward a low-carbon economy. Their expansion is driven by the growing integration of ESG principles into investment strategies, stricter regulatory frameworks, and rising demand from institutional investors.

The relevance of this study is determined by the need to comprehensively analyze the factors influencing the development of the green bond market and its adaptation potential in emerging economies. Despite the rapid growth of sustainable finance, institutional limitations and market inefficiencies continue to constrain the development of this segment, particularly in Kazakhstan.

The aim of the study is to identify key trends in the development of the green bond market and ESG investment practices, as well as to examine the factors influencing their evolution in Kazakhstan's financial system.

To achieve this aim, the study addresses the following objectives: to analyze the characteristics of green bonds as a sustainable finance instrument; to examine global trends in the green bond market; to assess the impact of ESG factors on investment decisions; to evaluate the development of green finance in Kazakhstan; and to identify key constraints and future prospects.

The study is based on a review of academic literature, reports from international organizations in sustainable finance, and relevant regulatory documents governing green economy development and financial markets.

The methodological framework combines qualitative and quantitative approaches. The qualitative component includes institutional and comparative analysis of green bond market development and ESG regulatory frameworks across regions. The quantitative component relies on secondary data from international sources such as the Climate Bonds Initiative, the World Bank, and the OECD.

For analytical and forecasting purposes, the study proposes the application of machine learning models, including Long Short-Term Memory (LSTM) networks and Transformer-based architectures, which are widely used for financial time series forecasting. The analysis considers key variables such as green bond issuance volume, ESG indicators, macroeconomic conditions, and institutional factors.

Comparative analysis is applied to highlight differences between developed and emerging markets, with a particular focus on Kazakhstan as an evolving green finance ecosystem.

The scientific novelty of the study lies in the development of a conceptual-analytical framework for assessing the green bond market in emerging economies, using Kazakhstan as a case study. Unlike previous research, this approach integrates institutional ESG indicators and macroeconomic drivers with the predictive logic of machine learning algorithms (such as LSTM and Transformer). The novelty consists in the theoretical justification of using these architectures as tools for analyzing non-linear dependencies within limited financial datasets, thereby establishing a comprehensive methodological basis for monitoring market dynamics and future development trajectories.

Literature review. In the study by Kudaibergenov S.K., Serikov G.S., and Ulakov N.S., the green bond market is considered a key instrument of sustainable development. The authors note the steady growth of the global GSSS market, whose volume in 2024 exceeded USD 1.04 trillion, with approximately 60% accounted for by green bonds. They emphasize the role of international standards (GBP, CBI) and regulatory mechanisms as key development factors, while also identifying limiting factors such as macroeconomic instability [1].

The further development of market drivers is examined in the study by Alashbaeva N.M., Misnik O.V., Lukpanova Zh.O., and Kaparova R.B., where the importance of the institutional environment and the implementation of international sustainable finance standards is emphasized. The authors highlight the key role of the Astana International Financial Centre (AIFC) and also point to the widespread adoption of blended finance as a global trend [2].

At the national level, the financing challenges of environmental projects are addressed in the work of Dosmuratov E.E., Niyazbekov R.K., Esentaeva A.A., and Aidarova A.B. The authors note the insufficient development of waste recycling infrastructure and stress the need to attract long-term financial resources. In this context, green bonds are viewed as a promising instrument for financing environmental projects [3].

Issues of the institutional and economic prerequisites for sustainable development are discussed in the work of Nurmaganbetov A.S., Shakeev S.S., and Serikbaeva B.M. The authors emphasize that the development of green entrepreneurship depends on government support, innovation-driven development, and the institutional environment, while also identifying barriers such as high investment risks and limited access to financing [4].

Modern methods of financial market analysis are presented in the study by Bekbolsynov A.S., Sembiyeva L., and Juočiūnienė D., where the possibilities of applying deep learning models are examined. The authors show that the use of LSTM and hybrid models (CNN-LSTM) with ESG factors improves the accuracy of financial market forecasting, including the green bond market [5].

Complementing this approach, Zhusupov E.M., Temirkhanov Zh.T., and Bekbolsynov A.S. examine the application of deep artificial intelligence in forecasting the green securities market. The authors emphasize that neural network models make it possible to capture the market's complex dynamics and provide more accurate forecasts than traditional methods [6].

Despite the growing body of research on green bonds, a number of issues remain insufficiently explored. There is still no consistent approach to evaluating their effectiveness in emerging markets like Kazakhstan, and findings on the role of regulation and ESG factors are often contradictory. In addition, although AI-based models show strong forecasting potential, their practical use in national contexts is limited. These gaps justify the need for further research focused on assessing the efficiency and risks of

green bonds using an integrated approach that combines institutional analysis and modern analytical methods.

The main part. Empirical analysis based on data from the Climate Bonds Initiative, OECD, and World Bank indicates that the global green bond market demonstrates a sustained upward trajectory over the 2021–2024 period. The total sustainable bond issuance reached approximately USD 966 billion in 2024, with green bonds accounting for nearly 58–60% of total issuance.

The observed growth pattern confirms that the green bond market has transitioned from an emerging niche segment to a structurally embedded component of global sustainable finance. The expansion is primarily driven by regulatory standardization, institutional investor demand, and integration of ESG criteria into capital allocation strategies.

Given the absence of uniform historical statistical series across all regions, this study applies a scenario-based analytical framework founded on the predictive logic of machine learning architectures (such as LSTM and Transformer dynamics). While direct model training is outside the scope of this paper, the study focuses on the theoretical substantiation of these models as essential analytical tools for processing non-linear ESG datasets under conditions of data scarcity.

Three development scenarios are considered:

- Baseline scenario: continuation of current regulatory and ESG trends
- Optimistic scenario: accelerated ESG integration and green taxonomy expansion
- Conservative scenario: macroeconomic tightening and reduced liquidity conditions

Under the baseline scenario, global green bond issuance is expected to stabilize at approximately USD 900–1,000 billion annually by 2026, with a persistent share of around 60%.

The analysis shows that Kazakhstan’s green bond market remains in an early developmental stage. However, institutional reforms led by the Astana International Financial Centre (AIFC) are creating favorable conditions for market expansion.

Key determinants include:

- regulatory incentives (subsidized coupon rates, guarantees)
- ESG disclosure improvements
- development of verification and certification infrastructure

Despite these improvements, the market remains constrained by limited liquidity, insufficient transparency, and underdeveloped secondary trading mechanisms.

Comparative results indicate significant asymmetry between developed and emerging markets:

- Developed markets: driven by private capital and ESG maturity
- Emerging markets: driven primarily by state policy and institutional support

Kazakhstan demonstrates a hybrid model, where public policy plays a central role in initial market formation, while private ESG-driven investment remains limited.

Although direct model training is not performed, the proposed framework aligns with widely used machine learning architectures in financial forecasting literature, particularly LSTM and Transformer models.

The superiority of hybrid architectures in capturing non-linear financial patterns is well-documented in recent literature, specifically regarding Informer-LSTM models and Decomposition Transformers [7, 8].

Existing studies confirm that such models:

- outperform traditional econometric approaches (ARIMA, VAR)
- better capture non-linear dependencies in financial time series
- improve forecasting accuracy when combined with ESG variables

Therefore, integration of ESG indicators with machine learning-based predictive logic enhances the analytical depth of green bond market assessment.

Table – 1

Global Green Bond Market Development (2021–2024)

Year	Total Sustainable Bonds (USD bn)	Green Bonds (USD bn)	Share of Green Bonds (%)	Data Source
2021	850 (approx.)	480	56	Climate Bonds Initiative
2022	900 (approx.)	520	58	OECD / CBI
2023	870	500	57	World Bank / CBI
2024	966	561	58–60	Climate Bonds Initiative

**compiled by the authors based on sources [9, 10]*

The data presented in Table 1 demonstrate a fluctuating but overall positive trajectory of the global green bond market over the period 2021–2024. Although total sustainable bond issuance experienced a slight decline in 2023 (from USD 900 billion to USD 870 billion) due to macroeconomic volatility, the recovery to USD 966 billion in 2024 confirms the market's long-term resilience and structural growth.

The observed growth trend reflects increasing investor confidence, regulatory support, and the institutionalization of ESG principles in financial decision-making. Despite minor fluctuations in total issuance volumes in 2022–2023, the overall trajectory confirms market resilience and gradual maturation. The dominance of green bonds within the GSSS market suggests that environmental objectives remain the primary focus of sustainable finance instruments globally.

Table – 2

Determinants of Green Bond Market Development

Factor Group	Key Driver	Mechanism	Empirical Impact
Regulatory	ESG standards (GBP, EU Taxonomy)	Standardization of issuance	Increased investor confidence
Regulatory	Government incentives	Subsidies, guarantees	Market expansion
Economic	Institutional investor demand	ESG portfolio allocation	Higher issuance volume
Economic	Cost of capital	Lower financing costs	Increased issuer participation
Institutional	Financial infrastructure	Exchanges, certification bodies	Improved liquidity
Institutional	AIFC development	Regional financial hub creation	Market formation in Kazakhstan
Technological	Machine learning tools	Forecasting and risk assessment	Improved market efficiency
Environmental	Climate policy	Decarbonization pressure	Structural demand growth

**compiled by the authors based on sources [9, 10]*

The analysis of Table 2 highlights that the development of the green bond market is driven by a combination of regulatory, economic, institutional, technological, and environmental factors. Among these, regulatory mechanisms such as ESG standards (including the Green Bond Principles and EU Taxonomy) play a central role in ensuring market transparency and reducing information asymmetry.

Institutional factors, particularly the development of financial infrastructure and platforms such as the Astana International Financial Centre (AIFC), are especially important for emerging economies, where private capital markets remain underdeveloped. Economic drivers, including institutional investor demand and cost of capital reductions, further stimulate market expansion by increasing issuer participation.

Technological advancements, particularly in machine learning and predictive analytics, contribute to improved risk assessment and forecasting accuracy, while environmental policies related to decarbonization create long-term structural demand for green financial instruments. Overall, the interaction of these factors confirms the multidimensional nature of green bond market development.

The findings of this study confirm that the development of the green bond market is not solely a financial phenomenon but a multidimensional transformation driven by regulatory, institutional, and technological factors.

First, regulatory harmonization through ESG frameworks such as the Green Bond Principles has significantly reduced information asymmetry and increased investor trust.

Second, institutional factors, particularly in emerging markets such as Kazakhstan, play a decisive role in market formation. The presence of the AIFC demonstrates that institutional architecture can partially substitute for underdeveloped private capital markets in early-stage financial ecosystems.

Third, the integration of a conceptual analytical framework based on machine learning logic represents a significant methodological advancement. Even without direct model estimation in this specific study, the proposed approach justifies how hybrid models combining ESG variables with deep learning architectures can enhance predictive accuracy for emerging markets like Kazakhstan [7, 8].

Overall, the results suggest that green bond markets evolve through a transition from policy-driven emergence to data-driven maturity.

Conclusion. The study examined key trends and development factors of the global green bond market, with particular attention to emerging economies, including Kazakhstan. The findings demonstrate that the green bond market is transforming into a structurally important segment of sustainable finance, driven by ESG integration, evolving regulatory frameworks, and growing institutional investor demand. It has been established that regulatory standardization, development of financial infrastructure, and climate policy initiatives serve as the primary determinants of market expansion. The scientific novelty of the research lies in the proposed integrated analytical framework that combines ESG institutional indicators, macroeconomic factors, and machine learning-based forecasting approaches for assessing the development of the green bond market. This framework enables a more comprehensive interpretation of both global trends and country-specific dynamics. From a practical perspective, the results of the study can be applied in shaping national sustainable finance policies in Kazakhstan, improving ESG disclosure mechanisms, and enhancing the efficiency of financial market regulation. The findings also emphasize the importance of strengthening institutional infrastructure, particularly the role of the Astana International Financial Centre, in accelerating the development of green financial instruments. Future research should focus on empirical modeling of green bond market dynamics using real financial datasets and advanced machine learning techniques to improve forecasting accuracy and strengthen policy relevance.

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ЖАСЫЛ ОБЛИГАЦИЯЛАР НАРЫҒЫ: ЖАҺАНДЫҚ ҮРДІСТЕР ЖӘНЕ ДАМУ ФАКТОРЛАРЫ

Аңдатпа

Зерттеу әдістемесі Climate Bonds Initiative, Дүниежүзілік банк және ЭЫДҰ сияқты халықаралық ұйымдардың қайталама деректеріне институционалдық және салыстырмалы талдау жасауды біріктіретін көпөлшемді тәсілге негізделген. Жұмыста сценарийлік тәсілге және машиналық оқыту алгоритмдерінің логикасына (LSTM және Transformer архитектуралары) негізделген аналитикалық фреймворк қолданылды, бұл статистикалық деректер тапшылығы жағдайында нарық динамикасын талдауға мүмкіндік берді. Зерттеу барысында «жасыл» облигациялар жаһандық тұрақты қарыз нарығының шамамен 60%-ын құрайтыны, ал

олардың өсуі реттеуді стандарттаумен және институционалдық инвесторлар тарапынан сұраныспен негізделгені анықталды. Дамыған және дамушы нарықтар арасында айтарлықтай құрылымдық алшақтықтың бар екені айқындалды. Қазақстандық нарық дамудың бастапқы кезеңінде екені сәйкестендірілді, мұнда «Астана» халықаралық қаржы орталығы (АХҚО) реттеушілік ынталандыру тетіктері мен сертификаттау инфрақұрылымы арқылы негізгі институционалдық драйвер ретінде әрекет етеді. Зерттеудің ғылыми жаңалығы ESG институционалдық индикаторлары мен макроэкономикалық факторларды машиналық оқытудың болжамды логикасымен біріктіретін интеграцияланған аналитикалық фреймворкті әзірлеу болып табылады. Бұл тәсіл дәстүрлі эконометрикалық модельдер шектеулі тиімділік көрсететін «жасыл» қаржының дамушы экожүйелеріндегі сызықтық емес тәуелділіктерді анықтау үшін терең оқытуды пайдаланудың теориялық негізін қалыптастырады.

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РЫНОК ЗЕЛЕНЫХ ОБЛИГАЦИЙ: ГЛОБАЛЬНЫЕ ТЕНДЕНЦИИ И ФАКТОРЫ РАЗВИТИЯ

Аннотация

Методология исследования базируется на многомерном подходе, сочетающем институциональный и сравнительный анализ вторичных данных международных организаций, таких как Climate Bonds Initiative, Всемирный банк и ОЭСР. В работе применен аналитический фреймворк, основанный на сценарном подходе и логике алгоритмов машинного обучения (архитектуры LSTM и Transformer), что позволило проанализировать динамику рынка в условиях дефицита статистических данных. В ходе исследования выявлено, что «зеленые» облигации составляют около 60% мирового рынка устойчивого долга, а их рост обусловлен стандартизацией регулирования и спросом со стороны институциональных инвесторов. Определено наличие значительного структурного разрыва между развитыми и развивающимися рынками. Казахстанский рынок идентифицирован как находящийся на ранней стадии развития, где Международный финансовый центр «Астана» (МФЦА) выступает основным институциональным драйвером через механизмы регуляторного стимулирования и инфраструктуру сертификации. Научная новизна исследования заключается в разработке интегрированного аналитического фреймворка, объединяющего институциональные индикаторы ESG и макроэкономические факторы с предиктивной логикой машинного обучения. Данный подход формирует теоретическую базу для использования глубокого обучения с целью выявления нелинейных зависимостей в развивающихся экосистемах «зеленых» финансов, где традиционные эконометрические модели демонстрируют ограниченную эффективность.