This study investigates the process of designing of financial instruments the green energy transition of the national economy in Ukraine based on the replication of the Polish experience of issuing green bonds. At present, there are significant gaps in building a financial instruments Ukraine's green energy transition. Replication of the Polish experience of using green bonds, as well as their issuance and circulation, becomes the basis for expanding the financial framework for the energy transition of the national economy.

An analysis of the dynamics in the issuance of green bonds in the global and local Polish financial markets has been conducted; factors that determine their cost at issue were identified based on the application of a regression model. It was established that the key factor affecting the cost of green financing is the scale of the issue, which increases its liquidity and allows them to be included in the portfolios of international institutional investors.

Based on a comparison of the institutional environment of the issuance of green bonds in Poland and Ukraine, directions for its improvement for the Ukrainian national economy have been identified. Special feature of the results is the combination of quantitative analysis of issuance parameters with institutional support for the development of green financing markets in Poland and Ukraine. That made it possible not only to identify key factors affecting the assessment of the value of green capital but also to substantiate the directions for improving the institutional support for financing the green transition for the Ukrainian economy.

The results could be implemented provided that the current legislation is improved to ensure external verification, the development of mechanisms for guaranteeing and insuring risks, as well as the orientation of issuances to large reconstruction and energy transition projects

Keywords: green bonds, financial support, digital financial architecture, green transition, finance, tokenization

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DEVELOPMENT OF FINANCIAL SUPPORT FOR UKRAINE'S GREEN TRANSITION BASED ON POLAND'S EXPERIENCE WITH GREEN BONDS

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1. Introduction

Green bonds are fixed-income financial instrument to support and finance environmental projects. These can include renewable energy, energy efficiency, green transport, and sustainable water management [1]. The importance of the United Nations Sustainable Development Goals and the climate goals of the Paris Agreement is growing, which, in turn, requires financial flows for implementation. Green bonds have become one of the main sources of sustainable financing since their inception in 2007 and have directed capital to projects to mitigate the effects of climate change [2]. Thus, the global green bond market has grown significantly, and the total issuance exceeded USD 3 trillion by 2024.

Green bonds act as a unifying chain of international capital markets with the implementation of environmental policies. The set of investment instruments for implementing sustainable development goals provides opportunities to receive additional benefits while de-risking [3]. However, the reliability of green bonds depends on the transparency of the regulatory framework, the standardization of green bond issues, as well as accurate and understandable reporting by issuers.

Ukraine requires not just reconstruction after a full-scale invasion but modernization of the entire energy system, taking into account the goals of sustainable development and the need to ensure sustainability, which is implemented on the basis of distributed energy generation. Therefore, the analysis and replication of the experience of the world market, Eastern European countries, in particular, Poland, in the issuance of green bonds allows to form an institutional and economic framework for the formation of financial instruments for the green energy transition of the national economy in Ukraine. This determines the relevance of the study on the use of green bonds for the energy transition of the national economy in Ukraine.

2. Literature review and problem statement

Review of scientific literature has shown that green bonds have begun to be studied not so long ago and in various aspects. Considerable attention in work [4] is paid to the regulatory features of green bonds, which includes acts and standards for regulating these financial instruments. The potential of green bonds in promoting the benefits of sustainable development and climate goals is studied, and their impact on environmental goals is assessed. Particular attention is paid to establishing benchmark indices of green bonds. At the same time, the issues of practical use of such instruments in local markets remain unresolved. The reason is the difference in national regulatory systems.

Investors are attracted to green bonds by their potential to generate competitive yield, while contributing to positive social and environmental outcomes. Challenges include standardization of reporting practices, harmonization of green definitions and taxonomies, development of reliable methodologies for measuring impact and mitigating the risks of greenwashing [5]. This is due to the lack of common standards for measuring environmental performance.

The integration of green bonds into global stock exchanges increases their accessibility and liquidity. Tokenization can improve the governance of green bonds by increasing transparency, digitization, and democratization of access [6]. Tokenization has the potential to play a larger role as it broadens the pool of capital available for green bond issuance [7]. However, the legal status of tokenized financial instruments remains unresolved. This is due to the lack of maturity of the digital financial infrastructure and the varying levels of legal recognition of tokenized assets.

Computational modeling is used to assess the impact of green bonds. Study [8] devises a multi-stage stochastic model for predicting green bond issuance using the filtered historical modeling (FHS) method to identify the most cost-effective conditions for issuing these bonds against the background of various risk factors.

The results of paper [9] demonstrate the stochastic behavior of green bond premiums. The proposed green bond pricing model with mean reversion of interest rates and green bond premiums can characterize the benefits of green bonds. However, objective difficulties in validating the model may arise in the analysis of practices in local markets.

In [10], a fuzzy option pricing method for green bonds is proposed. Based on the requirements of arbitrage equilibrium, the study relies on the Merton model of corporate bond option pricing.

Current studies of green bonds use computational and economic and mathematical methods. Thus, in [11], deep learning models are applied for time series analysis, in particular CNN (Convolutional Neural Network), LSTM (Long Short-Term Memory) and GRU (Gated Recurrent Unit). To describe the competitive interaction of innovation processes, in [12], models based on differential equations are used, which can be applied to describe the dynamics of scaling financial innovations, in particular green bonds. To estimate the stationary probabilities of the states of complex systems, in [13], the use of Markov models is proposed, which can be used to determine the conditions for changing risk levels. For early warning of corporate bond defaults, paper [14] demonstrates the use of decision trees, which can be used to assess the credit risk of green bond issuers. Machine learning methods are employed in [15] to predict changes in the liquidity of corporate bonds. Work [16] illustrates the possibilities of using kernel methods and semi-supervised learning for ranking complex financial and economic objects, which can be used to compare the investment attractiveness of different green bond issues. In addition, study [17] applied multi-criteria decision analysis (MCDA), which serves for the simultaneous use of qualitative (environmental) and quantitative (financial) indicators to make an objective choice by investors of a certain type of green bond issue based on simultaneous consideration of indicators of yield, risks, and environmental impact. Thus, computational modeling lays a reliable methodological basis for assessing green bonds, but its effectiveness is limited by data quality, methodological differences, and the lack of unified standards for assessing environmental impact.

Green bonds have become an important instrument in mitigating climate change, as noted in [18]. They are widely used by financial institutions and have recently been adopted by cities. In 2015, the Organization for Economic Cooperation and Development hypothesized that national governments could theoretically follow suit. In 2016, this hypothesis was positively confirmed by the Polish Ministry of Finance (PMF), which issued the first green sovereign bonds. In particular, six policy recommendations are proposed for issuing sovereign green bonds. Namely, the need for effective cooperation, the use of a green bond structure, the involvement of an independent reviewer, ensuring effective communication with investors, the promotion of green bonds and monitoring. However, the question of adapting this experience to different countries remains open.

A number of current studies confirm the existence of a stable “greenium” premium, according to which green bonds are characterized by a lower level of yield compared to traditional debt instruments with similar characteristics. This indicates the willingness of investors to accept lower financial yield in exchange for an environmental effect [19, 20]. At the same time, the value of greenium is not stable for all markets and all issuers. Its size depends on liquidity, rating, type of issuer, and trust in verification.

The authors of [21] consider the role of the banking sector in financing renewable energy in Poland. Among the instruments currently used to finance and support investments in renewable energy sources in Poland, the following groups can be mentioned. First, the system of subsidies for investments in renewable energy sources (funds provided at the central and local levels, EU funds, funds from the National Fund for Environmental Protection and Water Management and its voivodeship branches). Second, large investment loans (bank consortia) for the construction of power plants generating electricity from renewable energy sources. Third, preferential loans provided by the banking sector, project financing, public-private partnerships, leasing, green bonds, share issuance, green tariff and green premium, auction system, green certificate trading system, tax benefits. At the same time, the issue of combining banking, market and state instruments remains open.

Paper [22] examines the Polish green bond market. Green bonds have become a significant instrument in green finance, especially in Poland, where they are increasingly used to finance renewable energy, zero-emission transport, and green buildings. Disadvantages include significant transaction costs, lack of uniform standardization or the risk of greenwashing, especially when issuing bonds related to sustainable development. The development of green bonds in

Poland faces barriers related to the lack of green projects. The development of municipal green bonds in Poland is clearly hampered by high transaction costs and the lack of clear economic benefits for issuers. This is due to the complexity of project preparation.

The green bond market is growing rapidly and serves as a source of financing for energy transition, social impact investments, green economy transition, and climate change mitigation projects. The authors of [23] investigated the nature and direction of the relationship between green bond markets and traditional bond markets, as well as its stability during market shocks. They found similar patterns of behavior between green and traditional bond markets, but the green bond market is riskier than the non-green one, and the risk ratio of both bond markets changes. Investors are more likely to leave the green bond market and remain in the conventional bond market during periods of market shocks, such as the outbreak of the COVID-19 pandemic.

A comparative analysis of the European, Polish, and Ukrainian regulatory environments for the development of green finance was conducted. The document "Energy Policy of Poland until 2040" (EPP2040) [24] was analyzed to determine the strategic goals of Poland's energy policy. The "National Energy and Climate Plan" (NECP) [25] was used to clarify the practical goals of Poland's climate and energy policy, in particular regarding emission reduction, energy efficiency improvement and expansion of the share of renewable energy sources. The "Ukraine Facility" [26] was considered as a financial instrument of the European Union that defines the framework for Ukraine's support in 2024–2027 and creates a resource base for recovery and green transition. The "Ukraine Plan" [26] was used to analyze Ukraine's reform priorities, as it specifies the directions for using the funds of the "Ukraine Facility" and the conditions for approximation to European regulatory standards.

As a result, our review of scientific and applied literature creates a basis for understanding the main theoretical premises and approaches to the formation of the green bond market both on a global scale and in local markets, as well as the goals of using green bonds. Existing scientific developments allow to outline the contours of research areas, such as green bond tokenization, "greenium", modeling, the role of the banking sector, the role of local financial markets, assessing the impact of green bonds and their connection with sustainable development goals. At the same time, these works analyze mainly individual aspects of the green bond market. The combination of quantitative analysis of issuance parameters with an institutional comparison of Poland and Ukraine remains insufficiently studied. There is also a lack of studies linking the Polish experience with the "Ukraine Facility". This is due to the highly unpredictable military situation, the urgent need for Ukraine's post-war recovery, the limited range of financial instruments available to support the green transition, and the lack of practical experience in green bond issuance. In addition, significant gaps remain in the development of financial instruments for supporting Ukraine's green energy transition.

All this allows to argue that it is advisable to conduct a study aimed at expanding the financial support for Ukraine's green transition. Adaptation of the Polish experience in using green bonds, their issuance and circulation, becomes the basis for expanding the financial instruments for the energy transition of the national economy of Ukraine. It is advisable to pay special attention to determining the factors that define the cost of capital issuance and the institutional market conditions that affect its volume. This will allow to determine the features of adapting the Polish model of green debt to the needs of Ukraine's energy transition.

3. The aim and objectives of the study

The aim of our study is to compile recommendations for improving the financial support for Ukraine's green energy transition based on the use of Polish experience in issuing green bonds. This will allow the use of the Polish model of financing the green transition to expand the financial instruments for energy transition and green reconstruction of Ukraine.

To achieve this aim, the following objectives were set:

– to analyze the dynamics of green bond issuance in the global and local Polish financial markets and determine the factors that define their value;

– to devise directions for introducing financial support for the green transition of the Ukrainian national economy based on a comparison of the institutional environment for issuing green bonds in Poland and Ukraine.

4. Materials and methods

The object of our study is the process of building a financial framework for the green energy transition of the national economy in Ukraine based on the Polish experience of issuing green bonds.

The principal hypothesis assumes that the institutional support and market practice of issuing green bonds in Poland can be adapted as an effective model for attracting long-term capital for the "green transition" of the national economy in Ukraine.

This study is based on the assumption that the Polish green bond market, the features of their issuance and circulation, are the most transparent pattern for replicating the experience of attracting financing to ensure the "green transition" under the current conditions of the functioning of the national economy of Ukraine.

The work uses only public statistical data. The analysis is carried out for a statistically significant sample of parameters of the issuance of green bonds by Polish issuers, representative of the current state of the market.

The empirical basis is the global green bond market statistics from Statista [27], LSEG [28], data on green bond issues in Central and Eastern European countries, as well as a statistical panel of parameters for 28 green bonds by Polish issuers. Additionally, the regulatory acts of the EU and Poland (EPP2040 [24], NECP [25], documents "Ukraine Facility" [26]) and scientific publications from the Scopus and Web of Science databases were used.

Methodologically, our study combines content analysis of scientific and regulatory literature, methods of descriptive and comparative statistics, benchmarking of the green bond market in Central and Eastern European countries, as well as correlation and regression analysis of panel data on the characteristics of the issue of Polish green bonds. Data processing, construction of correlation matrices, estimation of linear regression parameters, and graphic visualization were performed in the MS Excel 365 environment, developed by Microsoft Corporation, USA.

5. Results of the study on expanding the financing of Ukraine's energy transition based on the issuance of green bonds

5. 1. Analyzing the dynamics of green bond markets and determining factors of their issuance cost

The global financial architecture by the beginning of 2026 has undergone significant technological and structural changes. The concept of sustainable development has also undergone transformation by changing from a strategy of introducing corporate social responsibility instruments to a holistic set of measures for financing the green transition. According to LSEG [28], revenues from the sale of environmental goods and services on the global market have exceeded the threshold of USD 5 trillion for the first time. The market value of the "green economy" is estimated at USD 7.9 trillion, which is 8.6% of the total capitalization of the global stock market [29].

In this context, green bonds are a critical instrument for financing capital-intensive energy transition projects, reaching a circulation volume of 3 trillion USD as of the third quarter of 2025 [29]. The value of green bonds issued worldwide from 2014 to 2023, by region, is shown in Fig. 1.

As can be seen from Fig. 1, the rapid growth of the global green bond market in 2014–2023 (cumulative issuance) increased from 37.0 billion USD to 587.7 billion USD (growth multiplier was 16 times). Europe remains the undisputed leader in green bond issuance throughout the period under study. In 2023, the total volume of green bond issuance amounted to 309.6 billion USD, or more than half of the global issue. The Asia-Pacific region – 190.2 billion USD, North America – 64.5 billion USD, other issuers, such as Latin America, Africa, and supranational organizations form only a peripheral share of the market. Thus, green bonds have already transformed from a niche financial instrument into an important mechanism for financing the energy transition, with high regional concentration.

The distribution of the use of proceeds from green bonds in the world from 2014 to 2023 by economic sectors is shown in Fig. 2.

The data shown in Fig. 2 demonstrate that in 2014–2023, funds raised through the issuance of green bonds were directed primarily to sectors directly related to the decarbonization of the economy and increasing resource efficiency. The largest share was received by energy – 35%, followed by buildings – 25% and transport – 19%; all together, these three areas accumulated 79% of all revenues.

Significantly smaller amounts of financing fell on the water sector – 7.4%, waste management – 4.9%, and land use – 4.26%. The lowest share fell on ICT and industry, about 1% each. This structure of the distribution of funds raised shows that on a global scale, green bonds are used as an instrument for financing the green energy transition, which also includes energy-efficient construction and environmentally friendly transport.

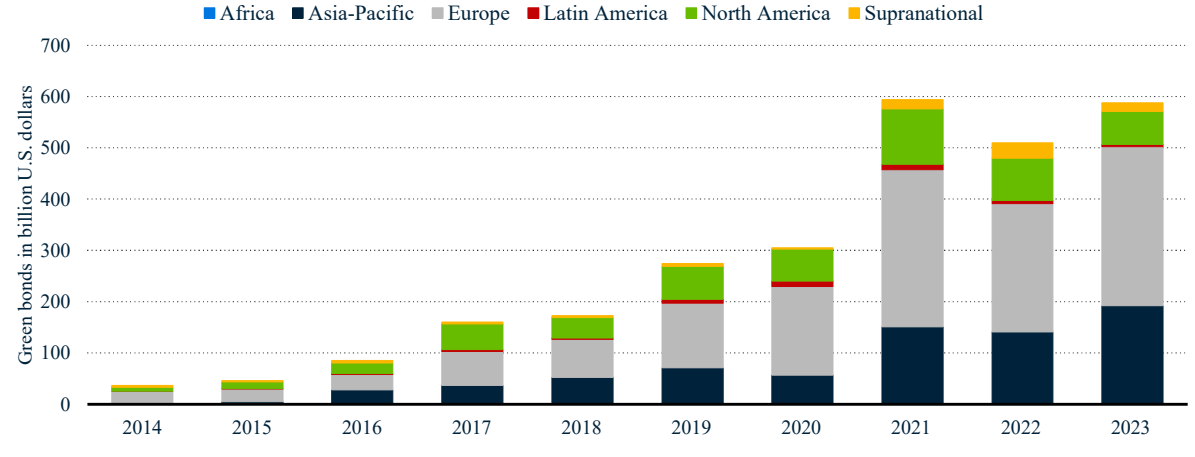

Fig. 1. Value of green bonds issued worldwide from 2014 to 2023, by region (in billion USD) [27]

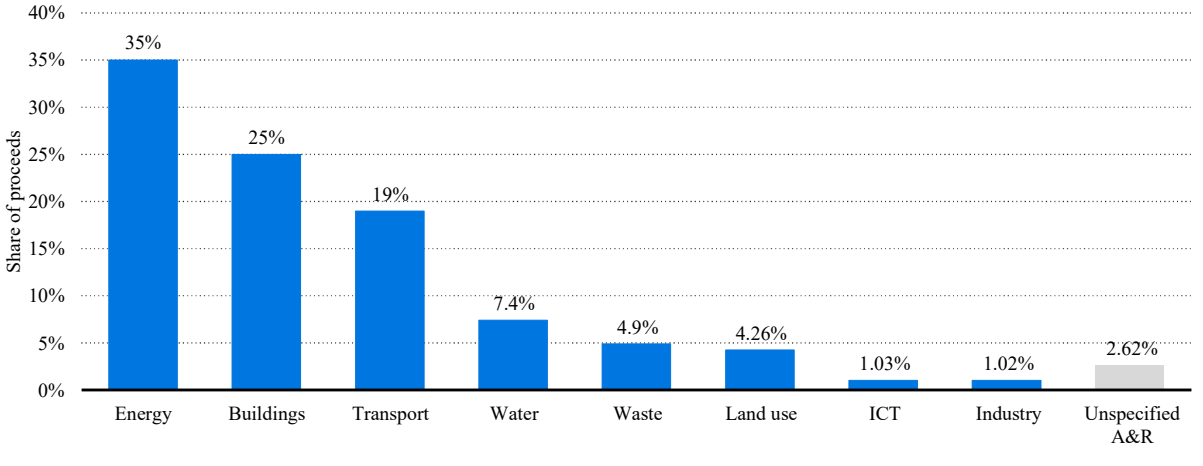

Fig. 2. Distribution of use of proceeds from green bonds worldwide between 2014 and 2023, by sector [27]

The data shown in Fig. 3 demonstrate that the issuance of green bonds was carried out mainly by the corporate and financial sectors, 30.7% and 27.3% of the total global issuance volume, respectively. That is, from the point of view of financing the green transition, the corporate and financial sectors are the main issuers, and the state provides guarantees and benefits for the issuance and circulation of such securities. This indicates the gradual integration of the principles of sustainable financing and green transition into corporate and financial strategies.

Analysis of the data shown in Fig. 4 reveals a high concentration of the green bond market by country: China – 83.51 billion USD, Germany – 67.51 billion USD, USA – 59.85 billion USD, Great Britain – 32.67 billion USD, Italy – 30.34 billion USD, and France – 29.97 billion USD. In the regional context, Europe dominates, which indicates a high institutional maturity of this green financing market.

But the European green bond market is structurally heterogeneous, with relatively small segments of it being Eastern European countries.

Benchmarking conducted based on the LSEG analytical section as of March 2026 shows that Central and Eastern European countries differ significantly not only in terms of green bond issuance volumes but also in terms of the degree of localization of this issuance (Table 1).

Among the Eastern European countries, Poland dominates, which in the sample demonstrates the highest share of green bonds in the total volume of bond issuance. This indicates the institutional development of the domestic green debt market. The institutional architecture of the Polish sustainable finance market, which includes the EPP2040 strategic framework and the NECP plan, can be replicated to form a developed green recovery financing market in Ukraine within the framework of the "Ukraine Facility".

Table 1

Benchmarking the green bond market in Central and Eastern Europe (LSEG, March 2026) [28]

Country	Country of issue			Country of incorporation			% local green bonds
	Green bonds, amount issued (USD)	All bonds, amount issued (USD)	%	Green bonds, amount issued (USD)	All bonds, amount issued (USD)	%	
Poland	868 142 943	20 796 237 951	4.17%	14 640 934 524	591 513 944 693	2.48%	5.93%
Czech Republic	414 416 707	574 791 152 792	0.07%	7 166 256 403	616 236 661 705	1.16%	5.78%
Slovakia	1 709 629 818	110 551 568 244	1.55%	2 894 733 063	117 839 580 339	2.46%	59.06%
Romania	271 822 704	113 509 775 227	0.24%	12 019 538 505	330 990 550 694	3.63%	2.26%

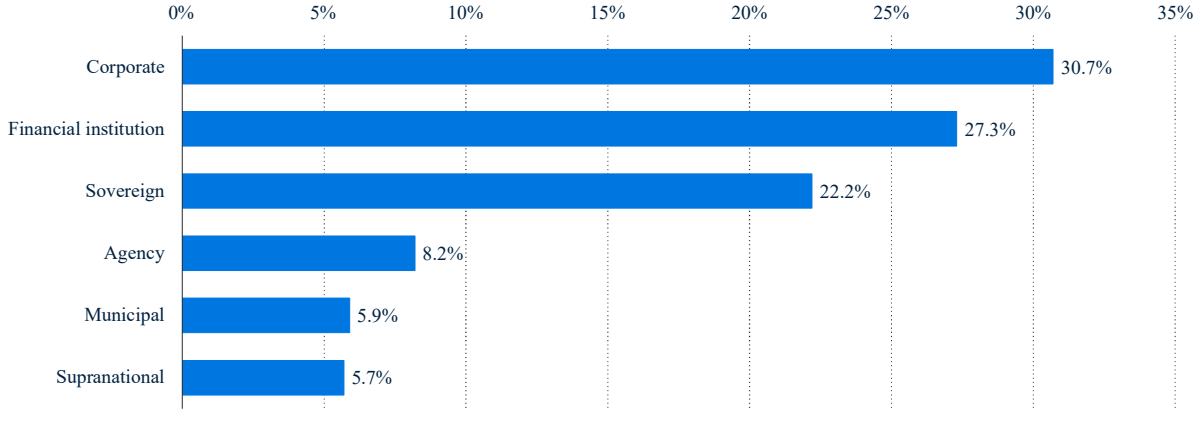

Fig. 3. Distribution of green bonds issued worldwide in 2023, by issuer type [27]

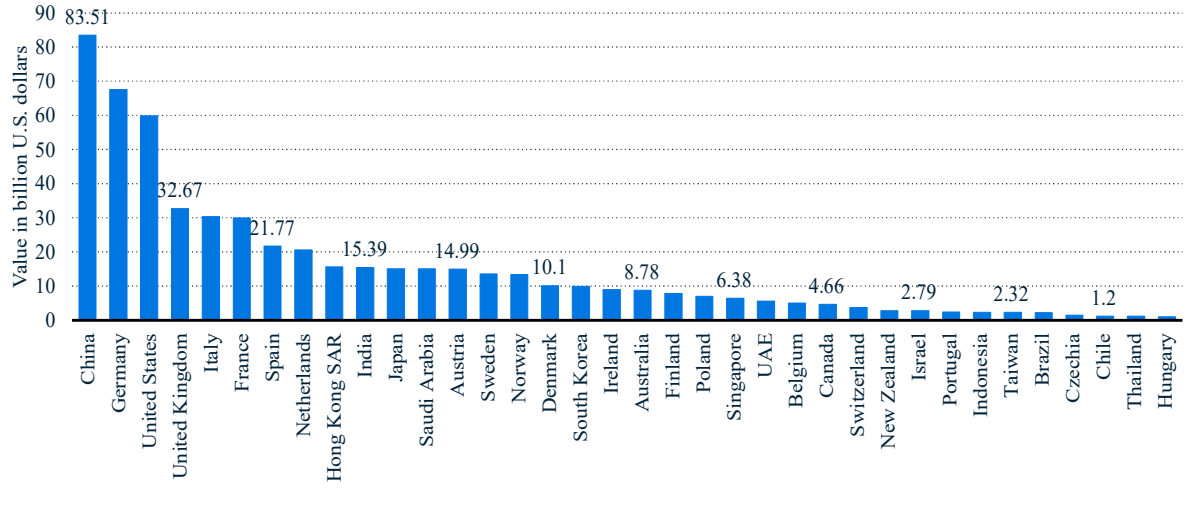

Fig. 4. Leading countries in terms of value of green bonds issued worldwide in 2023 (in billion U.S. dollars) [27]

Analysis of the "domestic" Polish bond market reveals that in general it is estimated at the equivalent of 20,796,237,951 USD. Moreover, 11.65% are ESG (Environmental, Social, and Governance) bonds, and Green Bonds are approximately 7%, which is shown in Fig. 5. Green bonds, whose issuers have the jurisdiction of other countries, also circulate on the Polish ESG bond market. Green bonds issued only in Poland amount to an amount equivalent to 868,142,943 USD (Amount Issued (USD) or 4% of the total volume of bonds (Fig. 6). Of these, by currency of issue, 62,180,215 USD or 7.16% are bonds issued in EUR, and 805,962,728 USD or 92.84% are bonds issued in Polish zlotys. Thus, the domestic market is dominated by green bonds issued in zlotys (PLN) 92.84%, which are traded on the local Warsaw Stock Exchange.

The cost of green bonds in Polish zlotys at a coupon yield ranged from 5.51 to 9.60%, and in euros from 5.62 to 7.61%, with a maturity of 3–5 years, regardless of the borrowing currency. That is, the spread on the coupon yield is smaller for bonds denominated in euros. Taking into account the stability of the Polish zloty against the euro, this indicates a higher cost of raising green capital on the local Polish market than for bonds denominated in the national currency. But the "green" transformation requires long-term capital – 10–20 years, the Polish corporate market provides the financing maturities of only 3–5 years. This creates a risk of non-refinancing (refinancing wall), which can be compensated by extending (prolonging) the terms of financing through mechanisms of state or European guarantees.

Further analysis of the current Polish green bonds reveals a significant divergence in spreads from 98 to over 3000 basis points (in fact, this is compensation for the risk premium). This proves that the presence of the Green Bond certification in itself does not create an unconditional "greenium" and does not protect the issuer from a harsh assessment of its underlying credit risk by the market (Fig. 7).

The most reliable assets on the Polish green debt market are bonds from the telecommunications sector (P4Spzo.o. with a spread of only ~ 98 bp) and renewable energy (Polenergia SA, ~ 147 bp). Investors assess their aggregate financial flow, which is stable and predictable, which allows them to attract the cheapest environmental financing with a yield of 5.2–5.7% per annum.

In contrast, green projects in the field of commercial construction and development, for example, the spreads of the "green" issue of the logistics operator 7R SA are – 455–496 bp, the developer Ghelamco Invest – 1712–3138 bp and the yield to maturity is 22–37%. This indicates high risks in the field of capital-intensive green construction and, accordingly, affects the cost of raising funds. That is, on the Polish corporate bond market, investors strictly distinguish green issues by industry. The environmental purpose of funds (Use of Proceeds) does not reduce (compensate) the assessment of the risks of developers' business models.

In addition, a study of the Polish capital market showed its low liquidity – insufficient for full financing of capital-intensive infrastructure projects (such as the EPP2040 energy strategy).

Large Polish banks and the corporate sector issue and place "green" bonds denominated in euros (Eurobonds) not in Warsaw. The issue is carried out in recognized financial hubs (jurisdictions) – Luxembourg, Ireland (Dublin), Germany (Frankfurt), or London, which operate under the rules of British or European law.

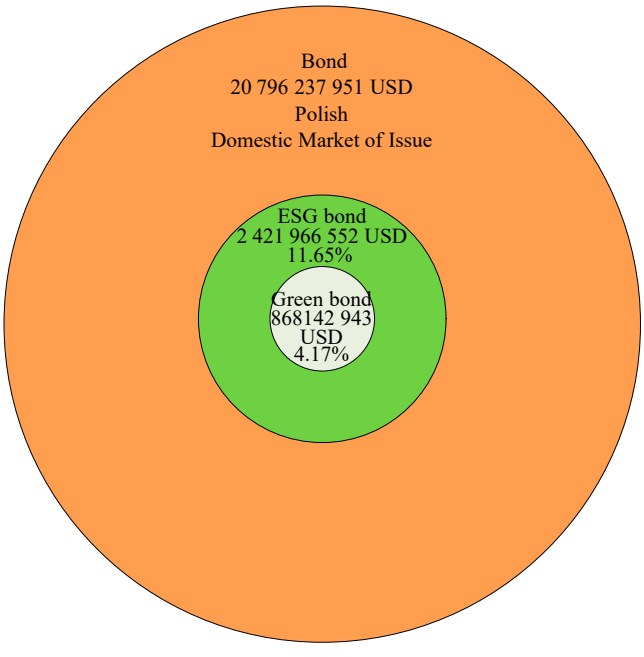

Fig. 5. Structure of the local Polish market for ESG (Environmental, Social, and Governance) bonds and green bonds as of March 2026 by jurisdiction Poland

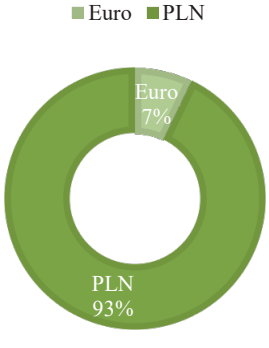

Fig. 6. Assessment of the local Polish green bond market as of March 2026 (Issuing country / issuing market)

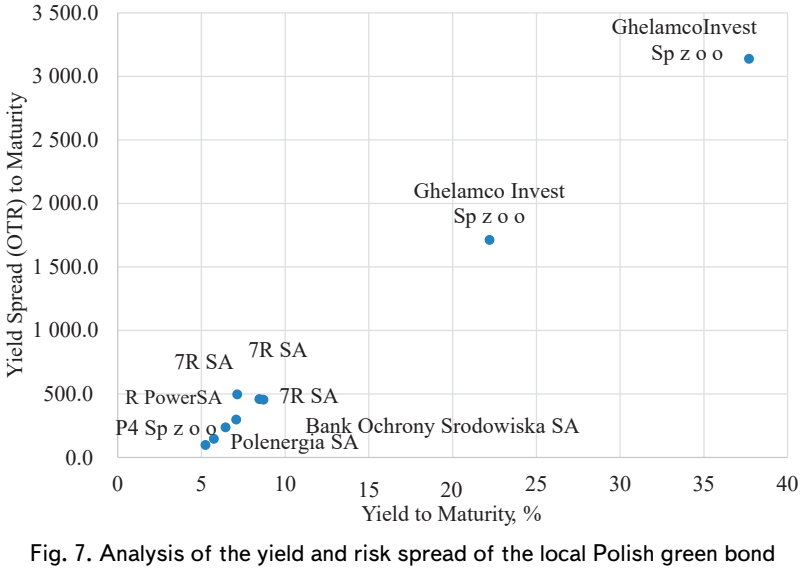

Fig. 7. Analysis of the yield and risk spread of the local Polish green bond market as of March 2026

That is why Eurobonds account for the lion's share of over 94.11% of Poland's green bond issuance. This indicates that the main buyers of green bonds are international institutional investors [28].

The cost of raising (coupon) "green" financing on the local market (PLN) is on average 7.7%, while on international markets (EUR, Japanese Yen) it reduces its cost to 3.6% (Fig. 8).

The analysis of capital raising on international markets reveals that 36.49% of the total issuance of "green" bonds is made up of Polish public sector issuers. The average term of capital raising is 13 years, and the average coupon rate is 2.04%, the target purpose is financing capital-intensive infrastructure projects with a long payback period, which is shown in Fig. 8. In contrast, corporate sector green bonds, which account for 63.51% of the issue, have an average maturity of 5 years and a higher coupon value of 5.63 on average.

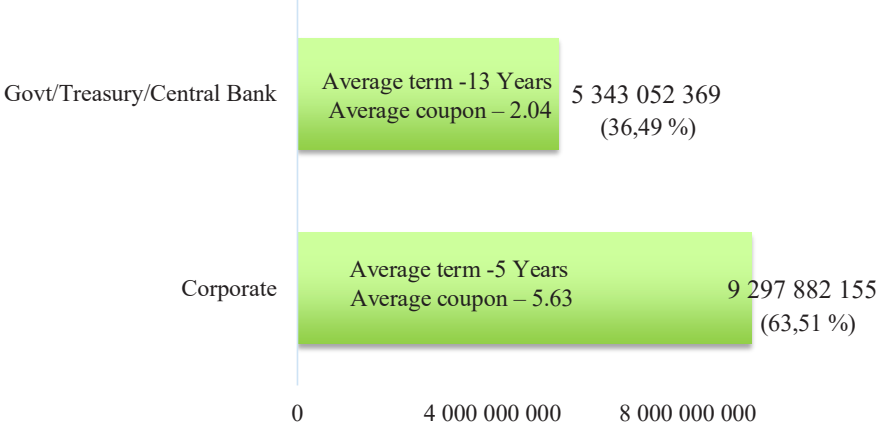

Fig. 8. Analysis of the structure of green bond issuance types by Polish issuers as of March 2026

The analysis of the credit quality of the issues reveals that the corporate and banking issues of the issuers: mBank, PKO Bank Polski, Bank Pekao have the status of Investment Grade. They are secured at the Senior Non-Preferred level and have the status of covered mortgage instruments (Covered Bonds).

Bonds of Polish issuers are clearly tied to the UN Sustainable Development Goals (most often – SDG 7, 9, 11). They are absolutely standardized, which is confirmed by external verification (Second Party Opinion, in particular Sustainalytics), which is a mandatory condition for the issue (CBI Aligned / Certified Green Bond).

The proceeds are allocated to renewable energy and green building projects.

Analysis of the type of coupons for green bonds of Polish issuers shows the dominance of classic fixed-rate debt instruments. Thus, 50.4% are plain vanilla fixed coupon bonds, which are a typical form of financing and provide predictability of value and stability of cash flows for investors. 43.7% are bonds with a transitional type of rate from fixed to floating rate – fixed-to-floating, which is typical for issues of banking and corporate issuers. This allows one to take into account changes in the macroeconomic environment and reduce interest rate risk. Floating rate bonds (margin over the index) make up only 5.9% of green bonds of Polish issuers. The structure of coupon payments of green bonds in Poland demonstrates a traditional approach to the issuance of debt instruments, which indicates the maturity of the market and its institutional integration into the fixed-income market segment.

The LSEG cross-section of the Polish green bond market shows a wide spread of risk spreads and returns, especially between sectors/branches of the economy (telecom/energy vs. development), that is, the purpose of financing. As academic study demonstrates, this is consistent with the classical approach of the presence of a "green premium" (greenium) in the average green bond market, which depends on the rating, issuer type, as well as market structure, and has a small effect and unstable magnitude [30].

Overall, the structure of the Polish green bond issuance market (plain vanilla fixed, fixed to floating, margin over index) shows that green bonds are embedded in the standard debt market structure. This increases compatibility with institutional investors' portfolios but requires constant risk monitoring, which is also consistent with the practice of certification and verification of debt securities issuances [31].

The plot in Fig. 9 shows the dynamics of Polish bond yields (BidYld) from the end of 2023 to March 2026 and demonstrates the increase in rates for corporate and government issuers during the weakening of the Polish currency against the Euro. Table 2 gives the average BidYld for Polish green bonds.

The analysis of Table 2 reveals the increase in the cost of financing for the banking sector and the energy sector in Poland when issuing green bonds and correlates with devaluation and inflationary processes.

In the context of green transition, such changes indicate an increase in the attractiveness of green bonds for investors, given the average increase in yield by 1–2 percentage points compared to traditional instruments.

Table 2

Table of average BidYld

Issuer (selection)	Average return, %	Trend for 2023–2026
Polish government bonds	3.1	Growth
Orlen SA	3.8	Growth
mBank SA	4.6	Volatile
Polenergia	5.9	Stable growth

To identify the key factors determining the cost of Polish green bonds, a study was conducted using a sample of key indicators characterizing the parameters of their issuance as of March 2026 according to LSEG data [28]. The sample covers 28 green bonds of Polish issuers (Country of Incorporation = Poland, Green Bond = Yes) according to LSEG data as of March 2026 by average values. This allowed to identify the following indicators (factors) that affect the cost of green financing:

– $Spread_{Worst,i}$ (Y) – spread to the worst-case scenario of maturity (bp);

– $Tenor_i$ (X_1) – term to maturity (years);

– $\log(Size_i)$ (X_2) – natural logarithm of the issue size (USD);

– $Govt_i$ (X_3) – dummy variable for sovereign issuers (Poland Republic of Government);

– $Bank_i$ (X_4) – dummy variable for banks (mBank, PKO BP, Pekao, Millennium, BOŚ);

– IG_i (X_5) – dummy variable for investment grade bonds;

– PLN_i (X_6) – dummy variable for the currency of issue (Polish Zloty / other currency);

– $Secured_i$ (X_7) – dummy variable of secured bonds (Senior Secured, Secured, Senior Preferred, Senior Unsecured, Senior Non-Preferred, (1/0));

– $Sustainalytics_i$ (X_8) – dummy variable of the availability of an independent expert opinion (Second Party Opinion) provided by the international ESG analytical company Sustainalytics BV.

The dependent variable was the yield spread to worst in basis points (Yield Spread (OTR) to Worst), which is a standard indicator of the credit premium, cleared of the influence of the risk-free rate. The study used a linear regression model with binary variables since some of the factors are qualitative in nature and can be correctly coded as 0/1. This makes it possible to assess the differences in the yield spread between groups, other things being equal, and to preserve the interpretability of the model [32]. Taking into account possible heteroscedasticity and the presence of outliers (in particular, very high spreads for individual corporate issues), the results are interpreted with caution.

To ensure the stability of the estimates, the issues of Ghelamco Invest Sp. z o. o. were excluded from the sample, the spread for which significantly exceeded the value for other green bonds and was identified as an outlier. According to the initial data in Table 1, a correlation matrix was built to determine the degree of relationship between the selected factors and the performance indicator using the MS Excel 365 program, developed by Microsoft Corporation, USA. The results are given in Table 3.

Correlation analysis revealed a high pairwise correlation between the explanatory variables of the issue volume (X_2), Investment Grade (X_5), and currency of issue (X_6), which may cause multicollinearity in the multifactor model (Table 3). Given the small sample size, X_5 and X_6 were excluded from the basic specification, and their impact is considered at the level of individual hypotheses. Also, the dummy variable of banks (X_4) was excluded due to its strong correlation with (X_7), which may increase multicollinearity. Other indicators are used further to test individual hypotheses. Based on the analysis, in particular on the selected variables and the results of the regression analysis, the following key hypotheses of the study can be formulated:

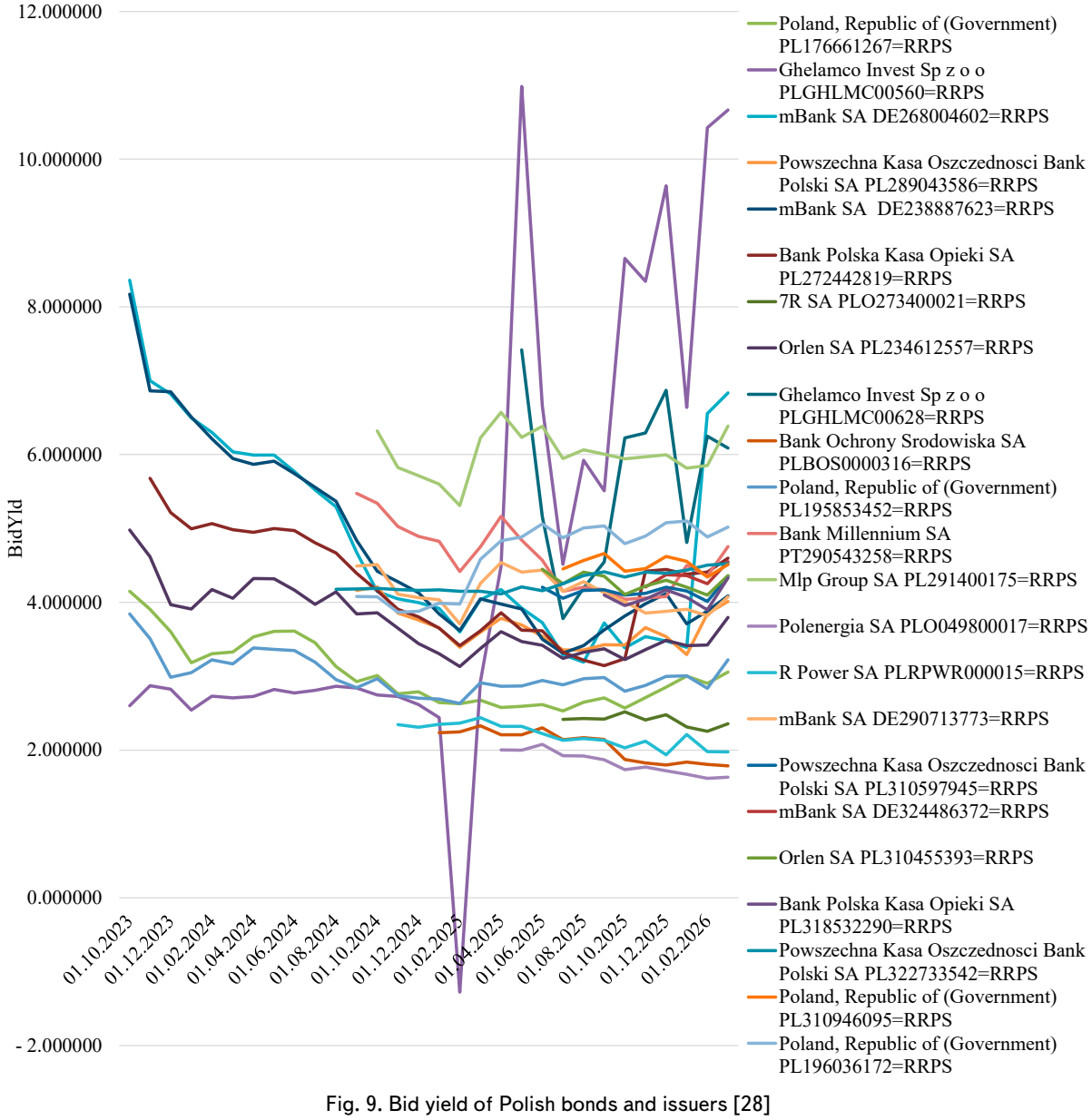

Fig. 9. Bid yield of Polish bonds and issuers [28]

Table 3

Results of correlation analysis of the spread to the worst-case repayment scenario

Indicator	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1	1	–	–	–	–	–	–	–
X_2	0.353	1	–	–	–	–	–	–
X_3	0.625	0.400	1	–	–	–	–	–
X_4	–0.170	0.353	-0.255	1	–	–	–	–
X_5	0.360	0.709	0.417	0.324	1	–	–	–
X_6	–0.261081028	–0.707121274	–0.267261242	–0.323975798	–0.639602149	1	–	–
X_7	0.228	–0.192	0.355	–0.785	–0.295	0.206	1	–
X_8	0.213	0.484	0.355	0.024	0.195	–0.177	–0.019	1
Y	–0.360	–0.836	–0.380	–0.384	–0.612	0.459	0.232	–0.410

Hypothesis 1. Issue size (X_2).

$H1_0$ – the logarithm of the issue size (X_2) does not affect the spread to the worst-case repayment scenario.

$H1_1$ – a larger log_size is associated with a statistically significant spread reduction (negative coefficient).

Hypothesis 2. Collateralization (X_7).

$H2_0$ – the collateralization status of the bond (X_7) does not affect the spread.

$H2_1$ – secured bonds have a lower spread compared to unsecured ones, that is, a negative coefficient at X_7.

Hypothesis 3. SPO from Sustainalytics (X_8).

$H3_0$ – the presence of a Second Party Opinion from Sustainalytics BV (X_8) does not affect the spread.

$H3_1$ – bonds with Sustainalytics-SPO have a lower spread compared to other issues, a negative coefficient at X_8.

To study the relationship between factors, hypotheses were tested. To test the hypotheses, an analysis of various models was conducted. In this work, linear regression models were selected for prediction.

To determine the form of the relationship between the studied parameters X_1, X_2, X_7, X_8, a regression analysis was conducted using MS Excel (in the "Data Analysis/Regression" menu). The results are given in Table 4.

Based on the results from regression analysis, the multiple regression equation takes the following form

$$Y = 1921.18 - 2.85 \cdot X_1 - 88.81 \cdot X_2 + \\ + 30.36 \cdot X_7 - 3.19 \cdot X_8. \quad (1)$$

Based on the estimation of the linear regression model of the spread to the risk-free rate curve for a sample of Polish sovereign and corporate bonds, it is shown that the model is generally statistically adequate ($R^2 \approx 0.72$). The F-statistic is 13.19 with a significance of $F \approx 0.0000159$, which indicates a statistically significant model overall at the 1% and 5% significance levels. However, the key determinant of the spread level is exclusively the scale of the issue, measured as the logarithm of the issue size. The coefficient on X_2 is negative and highly significant. Larger green bond issues are associated with a significantly lower risk premium, which is consistent with the hypothesis of a high liquidity effect of large issues. At the same time, the security status X_7 and the presence of an independent expert opinion (Second Party Opinion) provided by the international ESG-analytical company Sustainalytics BV X_8, as well as the maturity X_1 in the studied sample demonstrate a statistically insignificant effect on the spread. Although they remain theoretically justified factors and are reflected in the market structure (the difference between sovereign, bank, and high-risk corporate issues).

This indicates that for the Polish green bond market at the current stage, the key pricing factor is the market scale of placement, while the effects of security and external ESG verification need to be verified on expanded samples. Let's note that green bond issues of Polish issuers are standardized and have mainly fixed coupon rates, respectively, the factors of external verification and type of security have a limited impact.

Table 4

Regression analysis results

Indicator	Coefficient	Standard error	*t*-statistics
Y-intersection	1921.183891	320.7360906	5.989921147
Tenor (X_1)	–2.850469765	3.385448456	–0.841977009
log_size (X_2)	–88.81220696	16.79842144	–5.286937662
Securedi (X_7)	30.3657072	34.93389514	0.869233364
Sustainalyticsi (X_8)	–3.191195477	37.12593456	–0.085955964

Next, the study considered parsimonious single-factor specification (Fig. 10).

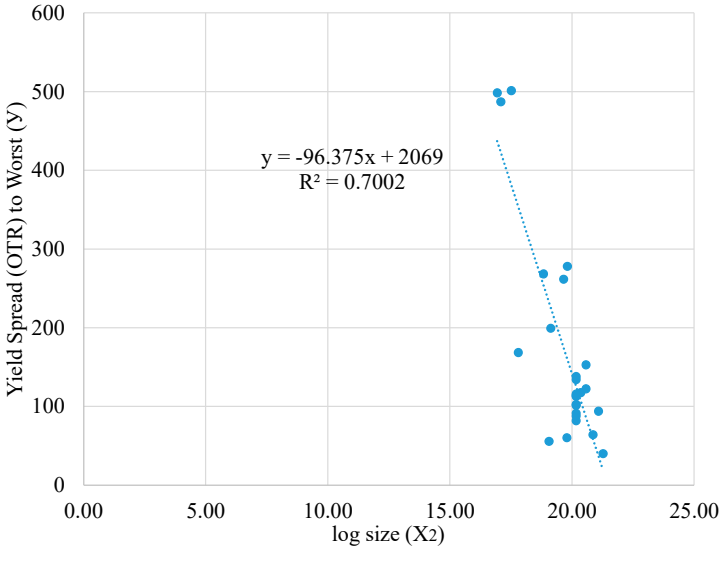

Fig. 10. Relationship between the impact of the issue scale on the spread to the worst-case repayment scenario

The final (parsimonious) one-factor model, which includes only the effect of the scale of issuance log_size (X_2), retains a high level of explanatory power ($R^2 \approx 0.70$ for a simple regression equation) and confirms the key role of the scale of issuance in the pricing of green bonds. The results have direct practical significance for the markets of Central and Eastern Europe. The Polish experience clearly demonstrates that the value of green bonds is determined not by the status of the issuer (state/corporation), but by structural characteristics: the scale of issuance,

the availability of collateral, and the reputation of the verifier. This confirms the previous hypothesis that, given the standard parameters of green bond issuances by Polish issuers, it is the scale of issuance that enhances liquidity. That is, the scale of issuance allows for the integration of green bonds into the portfolios of institutional investors, which allows for cheaper borrowing.

5. 2. Comparing the institutional environment of green bonds in Poland and Ukraine; designing a financial framework

Poland, as a leading economy in Central and Eastern Europe, demonstrates a unique trajectory of using these instruments for a radical restructuring of its carbon-intensive infrastructure. The experience of Poland is not only a regional case but also a strategic reference point for the post-war reconstruction of Ukraine according to the principles of "Build Back Better World / PGII The Partnership for Global Infrastructure and Investment" [33].

Ukraine already has a legal framework for the implementation of green bonds for financing the energy transition, but it is fragmented, that is, green bonds are synchronized with sectoral energy regulations. In Poland, on the contrary, a more mature multi-level system operates: national acts on bonds, renewable energy sources, energy, and special legislative acts – wind laws and, in addition, directly applicable EU regulations on EU Taxonomy [26, 27] (Table 5).

The EPP2040 Energy Strategy [24], adopted by the Polish Council of Ministers in February 2021, is based on three main pillars (directions): a just transition, a zero-emission energy system, and improved air quality. This strategy defines the path to climate neutrality, taking into account the national specificities of energy generation in Poland, in particular its historical dependence on coal, which still remains the highest in the EU.

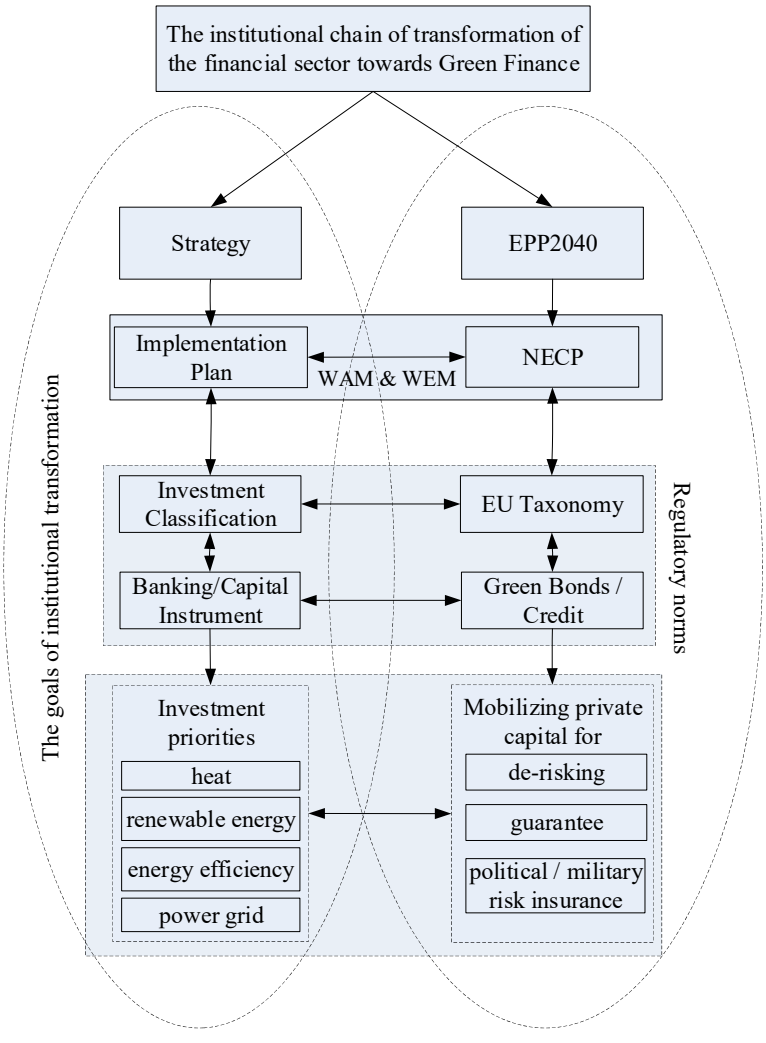

Fig. 11. Institutional transformation of the Polish financial sector towards ESG (Environmental, Social, and Governance) [24, 25, 34–36, 39, 40]

Table 5 compares the legal framework for the issuance and circulation of green bonds in Poland and Ukraine. Its analysis revealed that the application of the Polish experience for Ukraine is not only the possibility of using green bonds to finance renewable energy sources. The main conclusion is that a holistic institutional chain should be formed, as shown in Fig. 11. Poland's strategic documents and the general EU framework combine climate and energy goals with investment planning. The Ukraine Facility [26] creates a similar logic for Ukraine – reforms towards approximation with EU law and strategic investments [34, 35]. The Ukraine Facility program with a volume of 50 billion EUR for 2024–2027 is a key strategic financial instrument to support Ukraine's recovery [26]. It is built on three pillars, with a special focus on green transition and modernization (Fig. 12).

Pillar I (Ukraine Plan). Financial support for the implementation of reforms. Ukraine is obliged to achieve specific indicators, including the adoption of a National Energy and Climate Plan (NECP) and the implementation of legislation on the prevention of industrial pollution.

Pillar II (Ukraine Investment Framework). An investment program of 9.5 billion euros, aimed at attracting public and private investment. Moreover, there is a mandatory requirement to direct at least 20% of funds to climate goals.

Pillar III (Technical Assistance). Supporting Ukraine's institutional capacity to adapt to EU standards.

Up to now, the European Commission has provided guarantees and grants under the blended finance worth 5.7 billion EUR under the Investment Facility for Ukraine, mobilizing a total of 18 billion EUR in investment for rehabilitation, reconstruction, and modernization [43].

Green financing under the Ukraine Facility for Ukraine should be seen in the context of developing a cross-sectoral reconstruction logic, rather than as a separate environmental add-on. From an operational perspective, the Investment Facility for Ukraine provides guarantees, blended finance instruments, investment grants, technical assistance and provides risk coverage through European and multilateral financing agreements.

It should be noted that as of 2023, Poland and Ukraine had different development models and structures of the electricity sector (Table 6). Poland maintained a higher absolute electricity production, but its energy balance continued to rely heavily on coal, even with a record increase in the share of renewables to 26%. Ukraine, on the other hand, produced less electricity because of war and damage to its energy infrastructure, dominated by nuclear power, which provided 52 TWh in 2023 and remained the main source of electricity in the country. The Polish energy

system is rapidly evolving towards the development of renewable energy sources and is gradually reducing the share of coal.

Studies have shown that the transformation of Poland's energy sector requires enormous financial resources. The investment needs to achieve the EPP2040 goals in the fuel and energy sector are estimated to be around EUR 200 billion, and the total cost of the energy transition by 2040 could reach PLN 1.6 trillion [46]. Such a scale of financing is not possible without attracting private capital and using innovative instruments such as green bonds.

Poland is a global pioneer in the field of green bonds, having issued the first ever sovereign green bonds in 2016, for which it received the Green Bonds Pioneer Awards from ICMA [47, 48].

The effectiveness of green bonds is based on transparency in the use of proceeds. According to the ICMA Green Bond Principles (GBP), issuers are required to clearly define the categories of projects to be financed [47, 48].

Table 5

Comparison of legal frameworks for green bonds in Poland and Ukraine

Study aspect	Poland	Ukraine	Essence	Documents
Green bonds as a recovery instrument	In Poland, the issuance of green bonds operates within the framework of general legislation on bonds and, for the European standard, within the framework of Regulation (EU) 2020/852 establishing a classification system for sustainable investments (EU Taxonomy) and Regulation (EU) 2023/2631 on European Green Bonds, which sets out uniform requirements for the use of the designation «European Green Bond» EuGB	Ukraine already has a legislative framework for issuing green bonds: the law on capital markets provides for green bonds as securities, the proceeds of which must be used exclusively to finance or refinance an environmental project	It is a natural instrument for rebuilding infrastructure: it can be used to finance grids, renewable energy sources, energy efficiency, transport, and municipal infrastructure	EU Regulation 2020/852 on sustainable investment [34]; EU Regulation 2023/2631 on European Green Bonds [35]; On bonds [36]; Law of Ukraine "On Capital Markets and Organized Commodity Markets" [37]
Green bonds: availability of special regime	In Poland, there is a general law on bonds – Ustawa o obligacjach; it regulates the issuance of bonds in general. For "European Green Bonds" there is a special EU Regulation 2023/2631 on European Green Bonds	Law No. 3480-IV contains Article 18 "Green Bonds". The law explicitly states that green bonds are bonds whose prospectus/issue decision provides for the use of funds exclusively to finance an environmental project or its stage; the issue may be carried out by a person implementing or financing an environmental project	In Ukraine, green bonds are already explicitly defined in national law. In Poland, the issue is carried out within the framework of general law and a special European standard	EU Regulation 2020/852 on sustainable investment [34]; EU Regulation 2023/2631 on European Green Bonds [35]; On bonds [36]; Law of Ukraine "On Capital Markets and Organized Commodity Markets" [37]
Linking financing to energy transition goals	In Poland, the «Polish Energy Policy until 2040» and the «National Energy and Climate Plan» form a coherent system: a long-term strategy and implementation plan in the field of energy and climate. This simplifies the targeting of state, bank, and European funds to priority sectors	In Ukraine, a similar system could look like the Ukraine Facility and a national energy and climate action plan and national sectoral acts, which would allow for the financing of reconstruction to be combined with green modernization, rather than simply recreating the pre-war situation	This is most consistent with the logic of Build Back Better / PGII. Reconstruction should create more resilient and technologically advanced infrastructure, not just repair losses	"Ukraine Facility" [26], "Energy Policy of Poland until 2040" (EPP2040) [24], "National Energy and Climate Plan" (NECP) [25]
Energy transformation towards renewable energy sources and their support	Basic act – Act on Renewable Energy Sources of Poland. Regulates the conditions for carrying out activities related to the production of electricity from Renewable Energy Sources, in particular for micro and small installations	The basic act is the Law of Ukraine "On Alternative Energy Sources". It provides for financing activities in the field of alternative energy sources from tariff sources, budgets, contributions, and other non-prohibited funds; it also contains incentive mechanisms – a "green" tariff, an auction price, and surcharges	Both countries have specific laws on renewable energy sources, but the Polish system is more deeply integrated with EU law and new sectoral reforms	Law of Ukraine «On Alternative Energy Sources» [38]. Law on Renewable Energy Sources of Poland [39]
Energy market financing	In Poland, the basic systemic act is the Polish Energy Law	The Law of Ukraine "On the Electricity Market" allows for the imposition of special obligations on market participants to ensure general public interests, with the definition of sources of financing and compensation; this is the legal basis for some of the transition support mechanisms	Ukraine relies more on PSO mechanics (Public Service Obligations) and special obligations; Poland relies more on a broader set of energy and special legislation on renewable energy sources	Polish Energy Law [40], "On the Electricity Market" [41]
Investment priorities: grids, renewable energy, energy efficiency, heat	The Polish transformation model involves financing grid infrastructure, renewable energy sources, and energy efficiency. According to the logic of the «Polish Energy Policy until 2040» and the «National Energy and Climate Plan», this is precisely where investments are oriented	Ukraine can transfer this template to the reconstruction of critical infrastructure: distributed renewable energy sources, resilient power grids, modernization of district heating, public buildings, local and municipal energy. This is consistent with the logic of the Ukraine Facility as an instrument for recovery, modernization and reform	This is a practical field for issuing green bonds and applying selection criteria aligned with the EU Taxonomy	"Ukraine Facility" [26], "Energy Policy of Poland until 2040" (EPP2040) [24], "National Energy and Climate Plan" (NECP) [25]

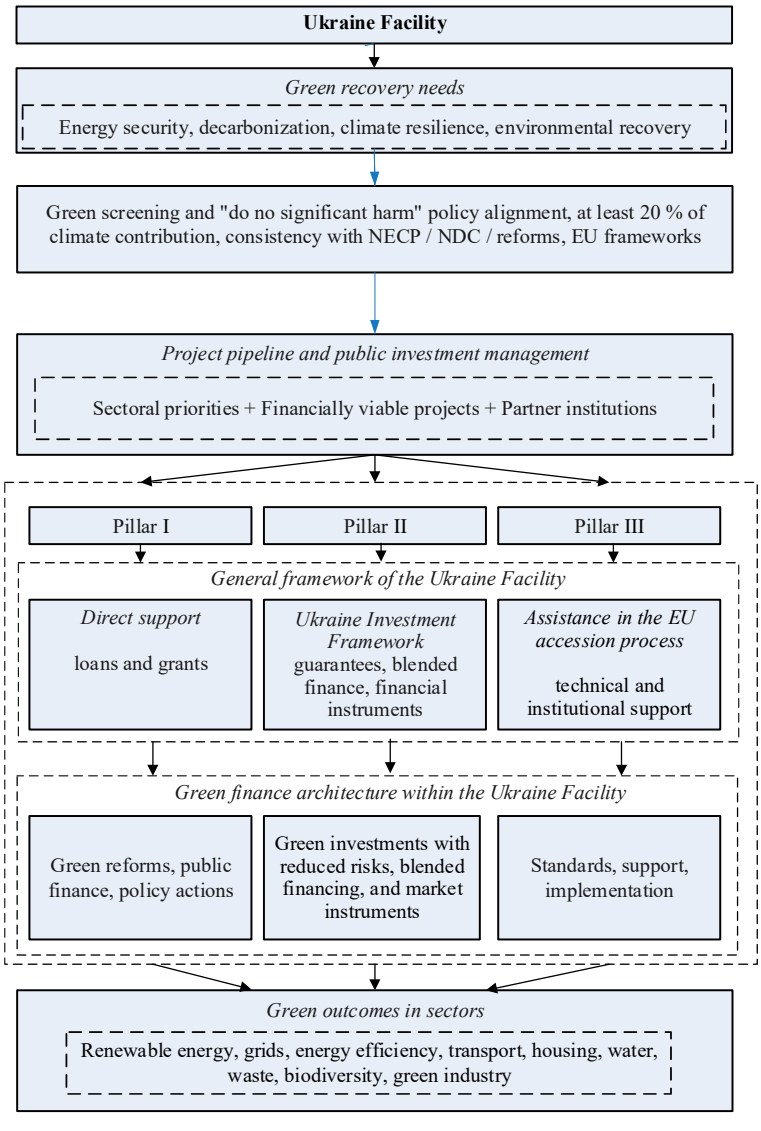

Fig. 12. The conceptual framework of the Ukraine Facility and its green financing logic [26, 42]

Table 6

Comparative characteristics of the structure of electricity generation in Poland and Ukraine in 2023 [43–45]

Indicator	Poland	Ukraine
Total generation, TWh	151.49	102.57
Nuclear power	–	50.4%
Coal, total	63.8%	21.1%
Gas	8.5%	10.6%
Oil/petroleum products	1.7%	0.1%
Hydro	1.3%	10.4%
Wind	14.6%	1.0%
Solar	8.7%	4.5%
Biomass	1.4%	1.0%
Other gases	–	0.9%
Low-carbon generation (renewable energy sources) total including hydro (excluding nuclear power)	26.0%	16.9%

For investors, the availability of external verification (Second-Party Opinion) is a key factor. PKO BP's green bonds received a positive opinion from Sustainalytics, confirming compliance with the EU taxonomy and the UN Sustainable Development Goals (SDGs 6, 7, 9, 11 and 12) [28, 49].

The Ukraine Facility, worth 50 billion EUR for 2024–2027, is a key instrument to support Ukraine's recovery [26]. The Polish experience in energy transition and the use of green finance should be adapted to ensure the effective use of these funds in line with the "green transition" principle. Pillar II of the program – the Ukraine Investment Framework (UIF) – aims to mobilize over €40 billion in investment by providing guarantees and grants to cover private sector risks [26, 43].

De-risking and Ukraine Investment Framework instruments [43, 50]:

1. Reducing credit risk for banks when financing renewable energy sources through First Loss Guarantees.

2. Stabilizing the income of renewable energy producers through a mechanism of competitive auctions and compensation for price differences through a joint initiative of the European Bank for Reconstruction and Development and the European Commission for the URMM (Ukraine Renewable Energy Risk Mitigation Mechanism).

3. Applying pilot schemes to protect investments in critical infrastructure through war risk insurance.

For full integration into the European financial system, Ukraine needs to implement the EU taxonomy standards. This will allow Ukrainian banks to classify their portfolios according to the requirements of the Green Asset Ratio (GAR) and the Bank Portfolio Alignment Ratio with the EU Taxonomy (BTAR), which is critical for raising capital through green bonds on international markets. The role of the Green Transition Office and the National Bank of Ukraine in 2025–2026 is to design a coordination mechanism between the state, business, and the banking sector to adapt these standards.

Our generalized model of green financing implementation for Ukraine, which combines the instruments of the Ukraine Facility, banking mechanisms for attracting capital and tokenized financial instruments, green bonds aimed at developing decentralization of the energy sector, is shown in Fig. 13.

The proposed model of green financing for Ukraine is based on a multi-level approach, within which strategic, institutional, financial, and sectoral elements are combined (Fig. 13).

Its basic core is the Ukraine Facility as an instrument that simultaneously forms a regulatory and strategic framework, provides mechanisms for guaranteeing and de-risking, as well as creates conditions for mobilizing international capital.

Considering that the current sovereign rating of Ukraine is at a speculative level, direct replication of the Polish experience is impossible without external guarantees. It is the Ukraine Facility funds that should act as a de-risking instrument, acting as a guarantor (First-Loss Guarantee) for green bond issues by Ukrainian state and systemic banks, raising their rating to investment grade. Given the high inflationary volatility of the war and post-war periods, financing long-

term reconstruction through floating rates creates excessive debt risk. For a successful institutional transfer, Ukraine must implement the EU Taxonomy standards. Banks operating in Ukraine must implement strict Green Bond Frameworks so that funds for infrastructure and housing reconstruction are verified by international auditors. Without this, the issue will not receive a green premium (Greenium).

For Ukraine, the implementation of Polish experience is important from the point of view of creating an effective green bond market. This requires the formation of three prerequisites: a state anchor (guarantees and grants); intermediary banks (certified and authorized by NBU); a standardized framework for green financing (requires reform of the current legislative and regulatory framework).

Given the high inflationary volatility of the war and postwar periods, financing long-term reconstruction through floating rates creates excessive debt risk.

For Ukraine, it is important that recovery programs focus on Eurobonds, and not only on the domestic market. Financing Ukraine's "green transition" cannot rely solely on the domestic capital market in hryvnia. The structural instruments of the "Ukraine Facility" should be aimed at designing an architecture of sovereign and quasi-sovereign Green Eurobond issues for access to a pool of international institutional investors.

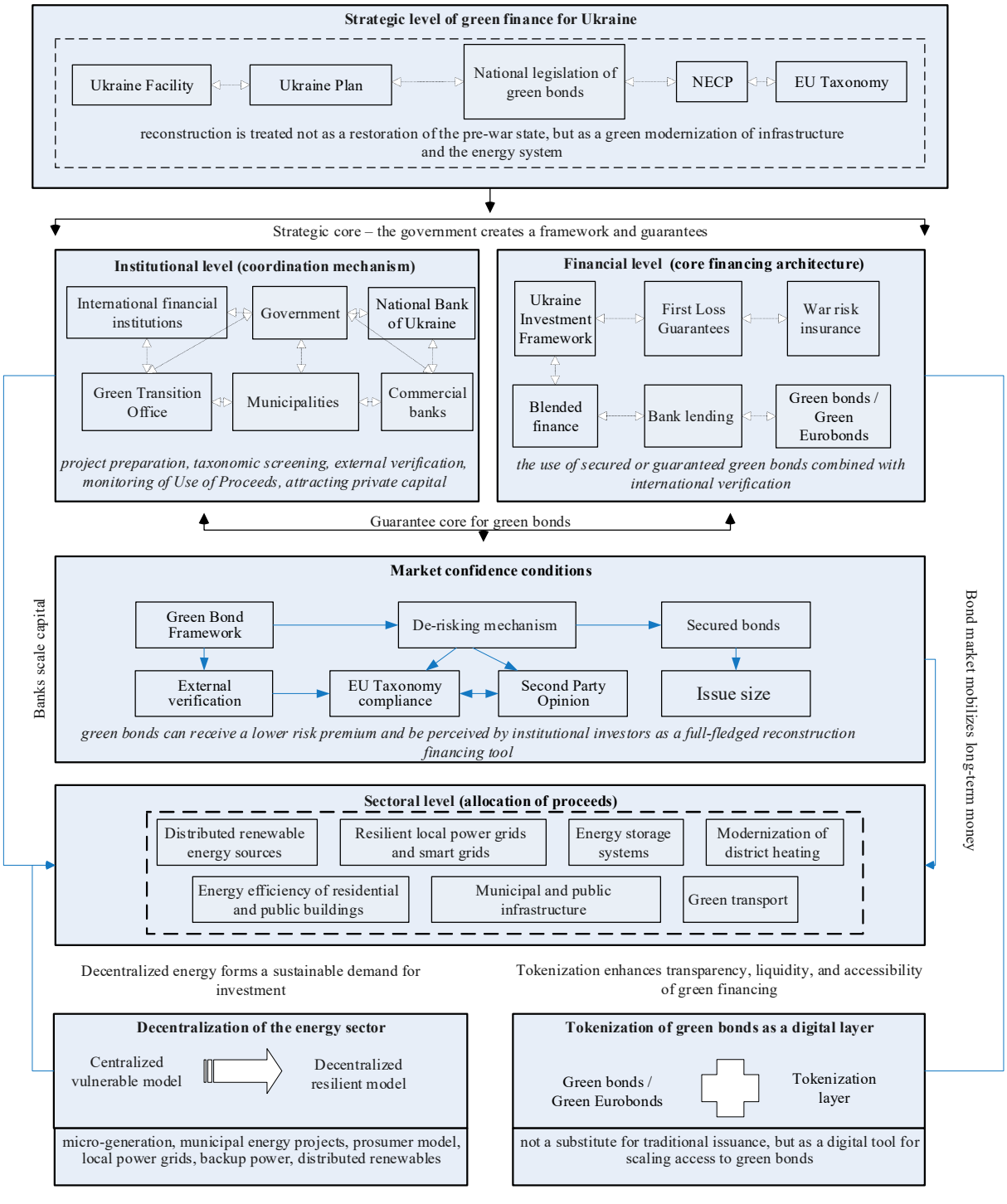

Fig. 13. Structural model of green financing for Ukraine

In this architecture, banks play an important role, acting as a transmission mechanism for the redistribution of financial resources between international financial institutions, government programs, and final recipients of investments. At the same time, green bonds are considered as a market instrument for long-term capital mobilization, capable of providing financing for large projects within the framework of green reconstruction.

The key feature of the proposed model is its focus not on the reproduction of the traditional centralized energy system but on the development of decentralized, sustainable, and low-carbon energy. This involves financing the development of distributed renewable energy sources, local grids, energy storage systems, the implementation of municipal energy projects and energy-efficient modernization of residential and public buildings. An innovative element of the model is the green bond tokenization. Tokenized green bonds can increase the transparency of the financial market, expand investors' access to financial instruments for green transition, and simplify monitoring of the targeted use of the funds raised.

6. Discussion of results based on investigating the Polish green bond market and the possibilities of adapting its experience for Ukraine

The results of our study proved that green bonds have become one of the main instruments for financing the green transition worldwide. The experience of the Republic of Poland has become the most valuable for its further replication in Ukraine. The empirical results of the study showed that the most influential factor on the cost of issuing green bonds is its volume. A comparative analysis of the legislative and regulatory framework for financing the green transition has made it possible to determine the priority areas of financing using green bonds. In addition, the conditions for the successful implementation of this financial instrument in Ukraine were determined. The results of our work are attributed to the performed empirical, theoretical, and institutional comparative studies on the issuance of green bonds, taking into account the global, in particular Polish, experience of using this financial instrument.

Analysis of the dynamics of green bond issuance on the global financial market has revealed that they have become an important instrument for financing energy transition (Fig. 1–3). The global growth in demand for ESG financial instruments is explained by the significant scale of issuance, and, accordingly, the possibility of their inclusion in the portfolios of institutional investors. Among the countries demonstrating positive growth dynamics of the green bond market, Poland should be highlighted, which has a developed infrastructure, the experience of building which can be replicated (Table 1, Fig. 4–6). Analysis of the LSEG sample as of March 2026 showed that the green bond market of Polish issuers is highly concentrated, institutionally structured, and oriented mainly to the international capital market. The significant role of sovereign and bank issuances in the total volume indicates that green bonds in Poland serve as a systemic mechanism for state support of green energy transition (Fig. 8, 9). The benchmarking study (Table 1) proves that the Polish experience is relevant for Ukraine, as it demonstrates the effectiveness of the model in which the state forms a market benchmark, and banks ensure the scaling of green financing of key areas of the green transition.

Unlike the results reported in [9, 19–21, 23], in which the use of green bonds is supported by a stable "greenium" premium compared to traditional instruments, empirical data for the Polish market indicate the absence of a universal premium for environmental friendliness. This is due to industry differences in issuers' business models, which also coincides with the approach in [23], which indicates an increase in the risks of the green bond market during shocks. Compared to work [21], our study expands the understanding of the role of the banking sector. Banks are considered not only as lenders but also as issuers of green bonds and guarantors of them.

When studying the factors that determine the cost of green bond issuance based on the results of regression analysis (Tables 3, 4, Fig. 10), hypothesis H1 was confirmed regarding the negative impact of the scale of issuance (X_2) on the yield spread to worst. This indicates the presence of a distinct effect of reducing the cost of green bond issuance with their large issuance volumes. In contrast, hypotheses H2 and H3 regarding the impact of security status (X_7) and the presence of a Second Party Opinion from Sustainalytics (X_8) were not statistically confirmed by the results of the analysis, although they remain theoretically sound. This indicates the need for further study using expanded dynamic samples and the inclusion of macroeconomic influencing factors, which will allow for a better identification of the role of instrumental characteristics and ESG factors in the formation of green bond spreads.

Based on a comparison of the analysis of the institutional environment for the issuance of green bonds (Fig. 11, 12) in Poland and Ukraine, the structure of electricity generation (Table 6), the need for and directions for implementing the Polish experience of financial support for the green transition for the Ukrainian national economy (Fig. 13) have been substantiated and determined. This will make it possible to determine the directions of reforming Ukrainian legislation on the issuance of green bonds and their main parameters of issue.

Polish experience proves that commercial banks (such as mBank and PKO BP) act as effective transmission mechanisms for the distribution of green capital. To implement the Partnership for Global Infrastructure and Investment program in Ukraine, it is advisable to direct 20% of the Ukraine Facility funds intended for financing the green transition to funding as an instrument for providing guarantees to Ukrainian and international banks. This will make it possible to multiply limited financial resources through the issuance of bank green bonds, ensuring strict compliance control and compliance with European ESG standards.

Our results should be interpreted taking into account several limitations of the study. First, the analysis is based mainly on secondary data and a static time frame, which does not allow to trace the dynamics of the behavior of spreads in the full financial cycle of green bonds circulation. Second, the regression estimation is performed on a relatively small sample of Polish green bonds, which reduces the statistical power of the tests and is sensitive to the presence of outliers.

The disadvantage of this study is the lack of a comparative model for several comparable countries, for example, for several countries in Central and Eastern Europe. Its construction would allow to check the stability of the results.

Also, the limited consideration of macroeconomic variables is a disadvantage. In the future, it is advisable to supplement the model with the influence of external factors: inflation, exchange rate, base interest rates, etc.

Further study should be directed at expanding the geography and time horizons of the sample, building multilevel panel models for several countries, including Ukraine.

7. Conclusions

1. Green bonds, as an instrument for attracting financing for the purposes of the green transition, evolved over 2014–2023 from a niche financial instrument to one of the key financial mechanisms. Thus, the total volume of annual issuance increased from 37.0 billion to 87.7 billion USD with the dominance of European issuers. In terms of the areas of use of funds in the green bond sector, decarbonization financing (energy, buildings, and transport) dominates, which collectively accumulates about 79% of the attracted resources, while other areas receive significantly smaller volumes. A comparative analysis of the countries in Central and Eastern Europe revealed that Poland has a relatively small absolute volume of green financing. However, it occupies one of the largest shares of green bonds in the structure of the domestic bond market and has sufficient liquidity depth, which gives grounds to consider it as a reference case for introduction in Ukraine. The combination of high growth rates and institutional maturity of the Polish market, the direction of financing for the energy transition creates an empirically sound basis for the formation of a framework for the green reconstruction of the national economy of Ukraine. A study of the local and international segments of the green bond market of Polish issuers revealed that its structure combines sovereign issues, bank Eurobonds and corporate debt, which have different yields, terms, and issue currencies. An analysis of coupon rates for green bonds showed that the cost of green capital on the local market is on average significantly higher than on the external one. Moreover, the issuance of green bonds in euros dominates, while "domestic" issues in zlotys remain relatively expensive and short-term. This is explained by the fact that access to the international capital market allows one to attract the liquidity of institutional investors. At the empirical level, this conclusion is confirmed by a regression analysis to determine the factors affecting the cost of green bond issuance. It has been substantiated that the key characteristic that determines the cost of a Polish green bond issuance is its volume, which is explained by the "scale" effect – the ability to access the portfolio liquidity of international institutional investors.

2. A comparative institutional analysis of existing and possible green financing models in Ukraine and Poland has revealed that for the national economy it should be rebuilt as a multi-level architecture. Replication of the Polish experience of issuing green bonds shows that the Ukraine Facility program performs the tasks of providing guarantees for issues, the banking system plays the role of a transmission mechanism for capital distribution. Given the need to decentralize the energy sector of the national economy in Ukraine, among the main areas of financing it is necessary to highlight renewable energy sources, storage systems, local municipal energy grids, and energy-efficient modernization of buildings. At the same time, green bond tokenization can significantly expand the range of investors while maintaining the price of their issue at small volumes. Thus, minimizing the cost of issuing green bonds is determined by forming a market confidence mechanism – the introduction of de-risking instruments: EU Taxonomy compliance (with external verification), large-scale issuance volumes to finance national projects, as well as the design of a national financial architecture.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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Authors' contributions

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