Information and analytical approaches to the transformation of environmental taxation in the context of stimulating green finance*

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Abstract

The article examines the effectiveness of environmental taxation in Ukraine in the context of stimulating green finance and ensuring sustainable development. The relevance of the work is due to the presence of imbalances between the volumes of environmental tax revenues and expenditures on environmental protection, which limits the possibilities of implementing environmental policy. The purpose of the study is to substantiate information-analytical approaches to assessing the effectiveness of environmental taxation based on an analysis of the dynamics of relevant indicators and the construction of forecast scenarios.

The methodological basis of the study is econometric modeling of time series taking into account structural breaks, as well as the use of an integral indicator - the coefficient of coherence of environmental revenues and green expenditures, taking into account the potential of using artificial intelligence methods to increase the accuracy of analysis and forecasting. The results of the study indicate the preservation of the structural gap between the fiscal capabilities of environmental taxation and the growing needs for financing environmental protection measures, which is confirmed by both retrospective analysis and forecast estimates.

The practical significance of the results obtained lies in the possibility of using the proposed approach to monitor the effectiveness of environmental policy, improve tax instruments, and increase the consistency between environmental revenues and expenditures in the context of the green transition.

Keywords

fiscal policy, environmental tax, green finance, climate challenges, information systems, forecasting, econometric modeling, time series, artificial intelligence, human capital, sustainable development

1. Introduction

In the current conditions of increasing climate challenges and the intensification of global priorities for sustainable development, the issue of transforming environmental taxation as a tool for ensuring a green transition is of particular relevance. Environmental taxes, along with other fiscal mechanisms, are considered an important tool not only for mobilizing budget resources, but also for stimulating environmentally responsible behavior of economic agents and financing environmental protection measures. At the same time, in the practice of the tax system of Ukraine, there is an insufficient level of coordination between the volumes of environmental tax revenues and expenditures on environmental protection. This limits the effectiveness of environmental taxation as a tool for supporting green finance and highlights the need to improve approaches to its assessment.

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Special attention is required to use information-analytical and econometric methods that allow a comprehensive assessment of the dynamics of environmental taxation, identify structural imbalances and form reasonable forecast scenarios for its development. In this context, it is important to form a system of indicators that can reflect the relationship between fiscal parameters and environmental priorities of state policy. At the same time, modern approaches to the analysis of such processes are increasingly based on the use of artificial intelligence technologies and machine learning methods, which allow processing significant amounts of data, revealing hidden patterns, and increasing the accuracy of forecasting fiscal and environmental indicators. This creates the prerequisites for increasing the validity of management decisions in the field of environmental taxation and green finance.

The purpose of the study is to substantiate theoretical and information-analytical approaches to assessing the effectiveness of environmental taxation in Ukraine in the context of stimulating green finance based on an analysis of the dynamics of environmental revenue indicators and budget financing of environmental protection measures, as well as building forecast scenarios for their development.

An analysis of scientific sources indicates an increase in attention to the issue of environmental taxation as a tool for ensuring sustainable development and stimulating green finance. A significant part of the research is focused on assessing the impact of environmental taxes on economic and environmental dynamics. In particular, in the works [2; 3; 9; 19] substantiates the relationship between environmental taxation, energy transformation and economic growth based on econometric analysis.

Significant attention is paid to the institutional aspects of the formation of green fiscal policy. Studies [1; 5; 14; 23] highlight the international experience of implementing environmental taxes, emphasizing the importance of the polluter pays principle and the integration of tax instruments with sustainable development policies.

A separate area of research is related to the development of green finance and its implementation, in particular, in the works [8; 19; 22] the role of fiscal instruments in mobilizing resources for financing climate initiatives and the development of carbon pricing mechanisms is emphasized.

A significant contribution to the development of research is made by works devoted to the digitalization of the financial sector and information and analytical support of fiscal processes. It should be noted that in the studies [6; 11; 12; 13] substantiates the role of digital technologies in increasing the efficiency of tax administration and transparency of financial resource management.

An important direction is the use of econometric and statistical methods for assessing the effectiveness of environmental taxation. Scientific publications [4; 21] and information resources [7; 16; 18] form the methodological basis for analyzing structural changes and ensuring the reliability of models for predicting fiscal indicators.

Attention is focused on the studies of Ukrainian researchers [1; 15; 20], which indicate the presence of imbalances between environmental tax revenues and expenditures, which limits the effectiveness of green fiscal policy.

It is emphasized that in the context of rapid digitalization and the growing role of data-driven management, artificial intelligence technologies are increasingly used in the field of public finance and environmental policy. The popularization of machine learning methods and data mining in the process of identifying hidden patterns [24], detecting nonlinear dependencies and increasing the accuracy of budget planning and forecasting procedures [6; 10; 25] is noted.

At the same time, the issues of integrating information and analytical approaches, econometric modeling and assessing the consistency of environmental revenues and green expenditures remain insufficiently researched, which necessitates further scientific developments.

2. Materials and Methods

The information and analytical basis of the study was formed on the basis of official open data of state institutions, in particular the analytical platform Open Budget [16] and the State Treasury Service of Ukraine [18]. Aggregated indicators of the implementation of the Consolidated Budget of Ukraine, the structure of tax revenues, as well as expenditures on environmental protection were used, which ensures a high level of reliability and representativeness of the empirical base. Additionally, statistical series were coordinated according to different sources in order to minimize information gaps and increase the comparability of data in dynamics. An important aspect is the integration of industry analytical materials and open information systems, which allows expanding the interpretative capabilities of the study [2; 8]. This approach ensures the formation of a holistic information circuit for assessing the effectiveness of environmental taxation in the context of fiscal policy transformation.

The methodological basis of the study is a combination of economic-statistical, econometric and information-analytical methods using digital tools for data processing and forecasting. The key element is the use of an extended regression model taking into account structural breaks, which allows us to adequately take into account the impact of crisis phenomena on the dynamics of environmental taxation [4]. The study used tools such as trend analysis, scenario forecasting and bootstrap estimation of confidence intervals, which allows us to form variable trajectories of environmental tax development [3]. Particular attention is paid to the integration of digital approaches to processing large amounts of budget data and building analytical indicators that reflect the relationship between tax revenues and green expenditures [10]. At the same time, modern information and analytical approaches can be expanded through the use of artificial intelligence methods. There is confidence that machine learning algorithms are able to take into account nonlinear dependencies, increase forecasting accuracy and adapt models to structural changes in green fiscal policy. Within the framework of this study, such approaches are considered as a promising direction for the development of analytical tools and will be used in the process of assessing the effectiveness of environmental taxation and its role in ensuring the green transition.

Given the need for a comprehensive assessment of the role of environmental taxation in the context of stimulating green finance, the formation of a system of indicators that reflect both fiscal effectiveness and the environmental focus of budget policy is of particular relevance. In modern conditions, the environmental tax is not only a source of budget revenues, but also a tool for stimulating environmentally oriented transformations of the economy [5; 14]. At the same time, the effectiveness of its functioning largely depends on the level of coherence between environmental tax revenues and financing of environmental protection measures. In this context, it is advisable to use an integrated system of indicators that allows assessing the relationship between the revenue and expenditure components of the state's environmental policy. The proposed approach involves analyzing the dynamics of key budget parameters, the effectiveness of environmental tax administration, and the coefficient of coherence of environmental revenues and green expenditures as an indicator of fiscal and environmental balancing. Such a system of indicators provides the opportunity to identify imbalances in financing the environmental sphere and form an analytical basis for making management decisions. The relevant estimated and statistical data for 2019–2025 are given in Table 1.

Table 1
Indicators for assessing the effectiveness of environmental taxation in the context of the green transition, UAH million *

Indicators	2019	2020	2021	2022	2023	2024	2025
1. Revenues of the	1289779	1376661	1662243	2196273	3104307	3587789	4337978

Consolidated Budget of Ukraine							
2. Tax revenues	1070321	1136687	1453804	1343225	1638085	2088283	2520339
3. Environmental tax (actual figures)	6093	5398	5989	4898	4966	5387	5605
4. Expenditures of the Consolidated Budget of Ukraine	1370113	1595289	1844377	3043499	4440940	4944026	5999467
5. Environmental protection expenses	9729	9057	10620	5227	6395	10 384	11772
6. Efficiency of environmental tax administration, %	98,1	100,6	108,1	72,8	129,9	156,3	119
7. Coefficient of consistency between environmental revenues and green expenditures	1,60	1,68	1,77	1,07	1,29	1,93	2,10

* based on source [16; 18]

3. Case study

The calculation of analytical indicators presented in Table 1 was carried out with the aim of comprehensively assessing the effectiveness of environmental taxation and the level of coherence between environmental revenues and financing of environmental protection measures. In particular, the effectiveness of environmental tax administration is defined as the ratio of actual revenues to planned (or potential) values:

$$R = (EP_fact / EP_plan) \times 100\%$$

where *EP_fact* – actual revenues from environmental tax; *EP_plan* – planned or potential revenues.

To assess the relationship between the revenue and expenditure components of environmental policy, the coefficient of coherence of environmental revenues and green expenditures was used:

$$K = EP / ENV_exp$$

where *EP* – volume of revenues from environmental tax; *ENV_exp* – environmental protection expenditures.

Interpretation of the coefficient K: at $K < 1$ there is an insufficient level of funding for environmental measures; at $K \approx 1$ – relative balance; at $K > 1$ – excess of fiscal potential over environmental expenditures.

In order to deepen the analytical assessment of the effectiveness of environmental taxation and determine its role in ensuring the green transition, it is advisable to use forecasting approaches that allow assessing the prospective dynamics of key fiscal and environmental indicators. This becomes especially relevant in the context of structural transformations of the Ukrainian economy, caused by both internal institutional changes and external shocks, in particular the military risks of 2014 and 2022 [12; 19]. In this context, the use of econometric modeling allows not only to reflect retrospective trends in the development of environmental taxation, but also to form reasonable

scenarios for its further transformation in the context of stimulating green finance. This creates a basis for assessing the sufficiency of environmental tax revenues in ensuring the financing of environmental protection measures and identifying potential imbalances in the public finance system.

Forecasting of revenues from the environmental tax was carried out on the basis of an extended econometric model with structural breaks, which takes into account the impact of the crisis events of 2014 and 2022 on the dynamics of the studied indicator [21]. The model was formalized in the form of:

$$EP_t = \alpha_0 + \alpha_1 \cdot t + \alpha_2 \cdot D22_t + \alpha_3 \cdot (D22_t \cdot t) + \alpha_4 \cdot D14_t + \varepsilon_t,$$

where EP_t – revenue from environmental tax in the year t; t – time variable; D22_t i D14_t – dummy variables of structural breaks; $\alpha_0 \ldots \alpha_4$ – model parameters; ε_t – random error.

The estimation of the model parameters was carried out using the Ordinary Least Squares (OLS) method, which ensures unbiased and efficient estimates of the regression parameters under the conditions of compliance with classical assumptions. The use of dummy variables allowed us to take into account the impact of structural breaks associated with the crisis periods of 2014 and 2022. In order to verify the correctness of the model specification and avoid false regression, standard diagnostic tests of time series were performed [21; 25]. In particular, the Augmented Dickey-Fuller test was used to check stationarity, the Durbin-Watson test to detect autocorrelation of residuals, and the White test to check heteroscedasticity. The results of the diagnostic analysis indicate the absence of critical violations of the main assumptions of the regression model, which allows it to be used for further analysis and forecasting.

The adequacy of the model is confirmed by the high value of the adjusted coefficient of determination (R^2adj = 0,880), which gives grounds to use it to construct basic, optimistic, and pessimistic forecast scenarios (Fig. 1).

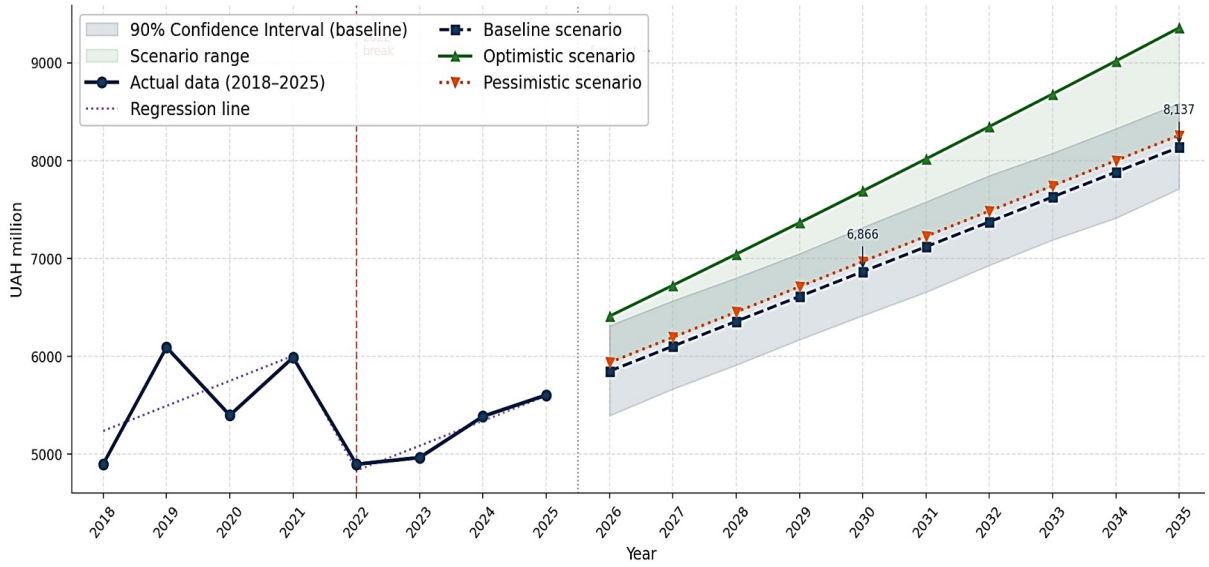


Figure 1: Environmental Tax Revenue Forecast in Ukraine (2018–2035): Three Scenarios with 90% Bootstrap Confidence Interval, UAH million

The formation of forecast scenarios was carried out on the basis of the parameters of the estimated econometric model, taking into account the variation of key coefficients and confidence intervals. The base scenario reflects the inertial development of the studied indicator in accordance with the estimated values of the model. Optimistic and pessimistic scenarios, respectively, were formed on the basis of the upper and lower limits of 90% bootstrap confidence intervals. This approach allows us to take into account the statistical uncertainty of the forecast and the variability of possible trajectories of the dynamics of the environmental tax depending on changes in economic and political conditions.

As the forecast results presented in Fig. 1 show, the revenues from the environmental tax in Ukraine demonstrate a general tendency towards gradual growth in all the scenarios considered.

The baseline scenario reflects the inertial continuation of existing trends, according to which the volume of environmental tax revenues by 2035 will reach about UAH 8.1 billion. The optimistic scenario, which envisages the intensification of environmental policy and harmonization with European green financing mechanisms, is characterized by higher growth rates, while the pessimistic scenario reflects the risks of a slowdown in economic activity in the conditions of maintaining military and structural restrictions.

Despite the positive dynamics, the results obtained indicate a relatively moderate growth of the environmental tax, which limits its potential as a key source of financing for environmental protection measures [9]. This indicates the need to increase the role of environmental taxation as a tool for stimulating the green transition, in particular by improving its rates, tax base and administration mechanisms.

At the same time, assessing the role of environmental taxation in ensuring the green transition requires an analysis not only of the dynamics of tax revenues, but also of the volume of financing for environmental protection measures. It is the ratio between mobilized financial resources and their use that determines the real effectiveness of environmental fiscal policy [22]. In this context, it is appropriate to analyze the dynamics of environmental protection expenditures, the forecast of which is presented in Fig. 2.

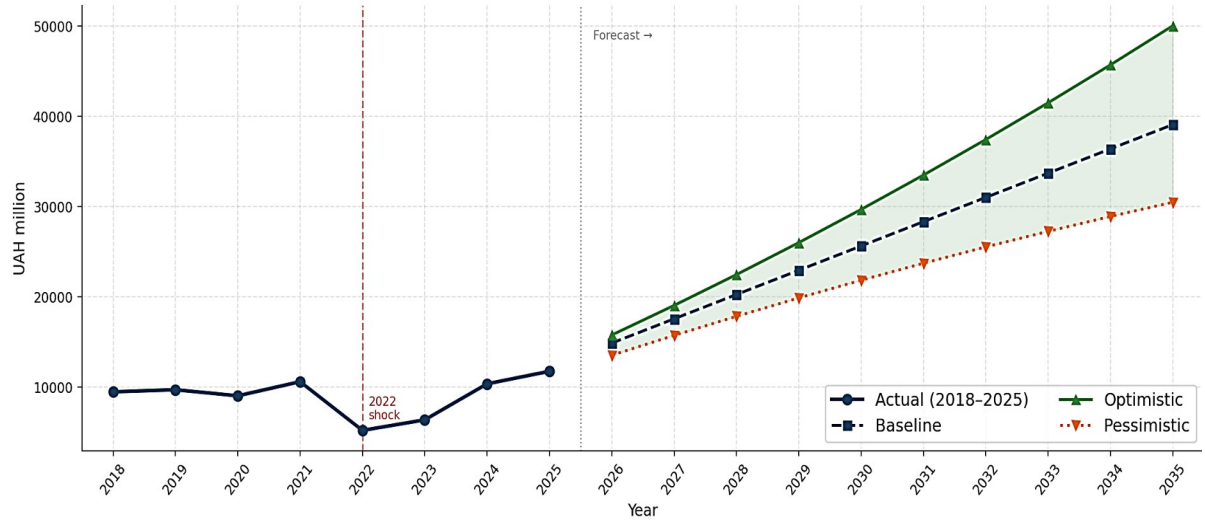


Figure 2: Environmental Protection Expenditure forecast (2018–2035), UAH million.

As the forecast results shown in Fig. 2 show, environmental protection expenditures demonstrate a more intensive growth dynamics compared to environmental tax revenues. In the medium term, a significant increase in the volume of financing environmental protection measures is forecast, which is due to both the growth of environmental challenges and the need to implement a green transition policy.

At the same time, this trend creates an increased burden on the budget system, since the growth rate of environmental expenditures outpaces the dynamics of the corresponding tax revenues [15]. This indicates the presence of a potential imbalance in the financial support of environmental policy and emphasizes the limited fiscal potential of environmental taxation in its current state.

In view of the above, there is a need for an integrated assessment of the relationship between environmental revenues and environmental protection expenditures. This approach allows not only to identify the presence of imbalances, but also to quantitatively assess the level of coherence of the state's fiscal and environmental policy.

The dynamics of the coefficient of coherence of environmental revenues and green expenditures as an integral indicator of the effectiveness of environmental taxation is presented in Fig. 3.

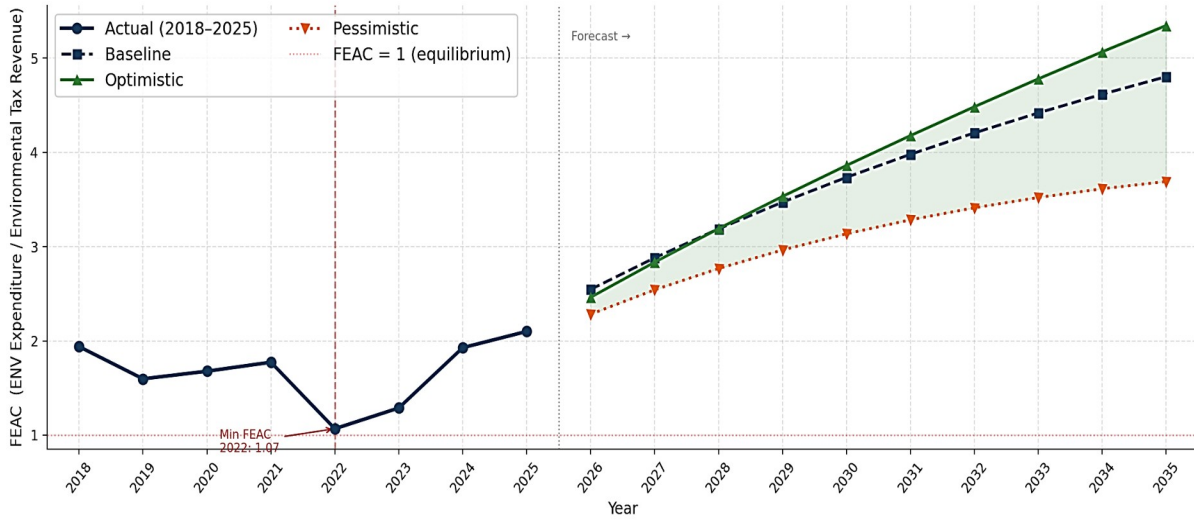


Figure 3: Dynamics and Forecast of the Coefficient of Alignment between Environmental Revenues and Green Expenditures in Ukraine (2018–2035)

As shown in the results presented in Fig. 3, the dynamics of the coefficient of coherence of environmental revenues and green expenditures reflects the presence of significant imbalances in the financial support of environmental policy in Ukraine. In the retrospective period, the coefficient values are characterized by significant variability, which is due to the high sensitivity of the ratio between environmental tax revenues and the volume of financing of environmental protection measures to structural shifts. A decrease in the value of the indicator during periods of economic instability indicates a deterioration in the coherence between the formation and use of financial resources in the field of environmental protection [13].

Forecast estimates indicate a gradual increase in the coefficient value in the medium and long term, especially under the baseline and optimistic scenarios. At the same time, despite the positive dynamics, the level of coherence of environmental revenues and green expenditures remains insufficient, which indicates the preservation of the structural gap between the fiscal capabilities of environmental taxation and the growing needs for financing environmental protection measures. This confirms the limited role of environmental tax as a source of ensuring the green transition in the conditions of its current institutional configuration.

The obtained results actualize the need to transform environmental taxation in the direction of strengthening its stimulating and regulatory functions, in particular by improving the parameters of taxation, expanding the base of environmental payments and integrating fiscal instruments with green finance mechanisms. This will allow to increase the level of coherence between environmental revenues and expenditures and ensure more effective implementation of sustainable development goals.

4. Discussion

The results obtained indicate the presence of a systemic mismatch between the fiscal capabilities of environmental taxation and the growing needs for financing environmental protection measures in Ukraine. Despite the positive dynamics of revenues from the environmental tax, their growth rates remain insufficient to ensure an adequate level of financial support for the green transition, which is confirmed both by forecast estimates and by the dynamics of the coefficient of consistency of environmental revenues and green expenditures.

From the standpoint of ensuring sustainable development, the results obtained indicate the need to rethink the role of environmental taxation in the public finance system [5; 20]. The administration of the environmental tax should be transformed from a tool for mainly fiscal budget filling into a mechanism for stimulating environmentally oriented behavior of economic agents and mobilizing resources to finance green investments [1; 14]. In this context, it is important to increase the level of consistency between environmental revenues and expenditures, which can be achieved by

improving tax policy parameters, expanding the scope of application of environmental payments, and integrating with climate financing instruments.

The results of the study confirm the feasibility of using information-analytical and econometric approaches in the process of assessing the effectiveness of environmental taxation, which creates the prerequisites for the further application of more complex data analysis methods [24; 25]. In particular, the use of artificial intelligence and machine learning methods is promising, which allow taking into account nonlinear dependencies, increasing the accuracy of forecasting, and adapting analytical models to structural changes in the fiscal policy of stimulating green taxes as a priority direction of the post-war reconstruction of the Ukrainian economy.

Conclusions

The obtained results of the study confirm that environmental taxation in Ukraine in its current form does not provide a sufficient level of financial support for the green transition. Despite the positive dynamics of revenues from the environmental tax, their growth is insufficient compared to the rate of increase in expenditures for environmental protection, which causes the formation of a stable imbalance in the system of financial support for environmental policy.

The practical significance of the obtained results lies in the possibility of using the proposed coefficient of coherence of environmental revenues and green expenditures as a tool for monitoring the effectiveness of environmental taxation and assessing the effectiveness of environmental policy through the level of coherence of environmental revenues and green expenditures. Its application allows identifying critical deviations between resource mobilization and the needs for financing environmental measures, as well as justifying management decisions in the field of budget planning.

In order to increase the effectiveness of environmental taxation, it is advisable to implement a set of practical measures, in particular: reviewing environmental tax rates taking into account the "polluter pays" principle; expanding the tax base by including new types of environmentally harmful activities; improving tax administration mechanisms using digital technologies and analytical platforms; expanding the powers of local governments in the field of administration, monitoring and control over the collection of environmental taxes, which will contribute to increasing transparency and efficiency in the use of financial resources at the local level; ensuring the targeted allocation of part of environmental revenues to finance environmental protection measures.

In addition, the study substantiates the feasibility of using artificial intelligence methods as a promising direction for the development of analytical tools in the field of green finance. The integration of machine learning algorithms will allow for increased forecasting accuracy, take into account nonlinear dependencies, and ensure a more flexible response to structural changes in fiscal and environmental policy.

An important direction is the integration of environmental taxation with green finance instruments, including carbon pricing mechanisms, green bonds and state support programs for environmental investments. In the context of the post-war recovery of the Ukrainian economy, such integration is of particular importance, as it forms the basis for combining reconstruction processes with the implementation of the goals of the green transition and ensuring the climate sustainability of the economy. This will allow for increased consistency between fiscal instruments and strategic goals of sustainable development, as well as ensuring more efficient use of financial resources.

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Declaration on Generative AI

The authors have not employed any Generative AI tools.

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