

Nataliia Levchenko,*DrHab (Government Administration), Professor,*

ORCID 0000-0002-3283-6924

e-mail: levchenko@zp.ua

National University Zaporizhzhia Polytechnic, Zaporizhzhia

Serhii Levchenko,*PhD (Management and Administration),*

ORCID 0000-0002-6569-909X

e-mail: fanatdroid@gmail.com

State Tax Service, Main Department in Zaporizhzhia region, Zaporizhzhia

ANALYSIS OF THE EFFECTIVENESS OF THE TOKENISATION MECHANISM OF «GUARANTEES OF ORIGIN» FOR ELECTRICITY AND ITS IMPACT ON THE «GREEN» TRANSFORMATION OF ELECTRIC POWER COMPANIES

Introduction. Digitalization of economic processes and search for innovative asset management tools determine current trends in the development of enterprises around the world. One of these tools is tokenization, which provides the transfer of tangible and intangible resources to digital form by issuing tokens representing the rights of ownership, use or disposal of assets. The introduction of the tokenization mechanism creates new business opportunities: increasing the liquidity of inaccessible assets, expanding access to financing, reducing transaction costs and creating transparent management mechanisms. Tokenization is of particular importance in the energy sector, where against the background of the Global course towards decarbonization and the development of renewable sources, there is a need to create transparent and reliable mechanisms for accounting and confirming the generated «green» energy. In this context, one of the key tools is the system of «guarantees of origin», which allows you to confirm the source of electricity production and ensure its further circulation in energy markets. It is the tokenization of «guarantees of origin» using blockchain technologies that can ensure a high level of transparency, reliability and security of data, reduce the risks of manipulation and increase the trust of consumers and international partners. However, like any management decision, the implementation of the tokenization mechanism of «guarantees of origin» requires a comprehensive assessment of its effectiveness, that is, the study of economic feasibility, assessment of potential benefits and possible risks, which determines the relevance of this study.

The analysis of literature sources shows that the problem of introducing tokenization of «guarantees of origin» is now at the stage of formation. Research is mainly focused on general issues of digitalization of energy markets, development of blockchain technologies and data verification mechanisms. The issues of comprehensive performance assessment, in particular economic feasibility, risk and benefit assessment for stake-

holders remain insufficiently developed. In Particular, Klimovich S. V. focuses on tokenization as an innovative method of attracting investment and money management, based on the use of distributed ledger technology, better known as blockchain [1, p. 97]. Cherep O. et al. consider asset tokenization as a strategic tool for transforming the investment environment in the context of digitalization of the global economy [2, p. 210]. Budnik V. reveals the conceptual foundations of digital assets, their differences and regulatory challenges [3]. I. Fedorenko. emphasizes the importance of asset tokenization, which consists in improving liquidity, reducing transaction costs, improving security and increasing the availability of investments. Tokenization, according to the researcher, creates more accessible and liquid opportunities for investment and circulation of various assets, facilitating their processing and contributing to globalization [4, p. 178]. Mironova O. notes the challenges and risks associated with the process of tokenization of enterprise assets. The author reveals legal and regulatory aspects that limit the integration of the latest technologies into traditional economic models [5]. Perebiynis D. considering the main challenges and risks associated with tokenization, focuses attention on technical problems and security issues [6, p. 210]. According to the results of the study, the scientist proves the need to adapt traditional financial models and regulatory framework to the challenges of the digital age, which will contribute to greater flexibility and efficiency of raising capital by tokenizing the assets of enterprises [7, p. 178].

Therefore, a review of scientific papers shows that most researchers consider the tokenization of assets through the prism of technological innovations, financial instruments and institutional changes. However, the very issue of the effectiveness of tokenization of «guarantees of origin» as a specific mechanism for the development of energy markets has been studied only in fragments. Insufficient theoretical elaboration of this prob-



lem in the scientific literature and the lack of developed practice of its application by domestic enterprises determine the relevance of further research in this direction.

The purpose of the article is to conduct a comprehensive analysis of the effectiveness of the tokenization mechanism of «guarantees of origin» of electric energy and assess its impact on the «green» transformation of energy sector enterprises.

Results.

Intending to accelerate the process of energy transition to a low-carbon economy, Ukraine, guided by the experience of the EU countries, is actively taking measures to attract investment in the «green» transformation of energy enterprises and the development of renewable energy sources. Among the measures taken, the introduction of a mechanism for «guarantees of origin» of energy deserves special attention.

The «guarantee of origin» of energy in accordance with paragraph 1 of the law of Ukraine «on amendments to certain laws of Ukraine concerning the restoration and «green» transformation of the energy system of Ukraine» dated June 30, 2023 for No. 3220-IX [8] is an electronic document formed on the basis of information from the Register of guarantees of origin of electric energy produced from renewable energy sources, which confirms that a certain amount of electric energy produced from renewable energy sources and has environmental value [8].

Some identify the mechanism of «guarantees of origin» with previous mechanisms for regulating the electricity market [9], such as trading in carbon quotas, carbon credits, etc., which were introduced with the signing of the Kyoto Protocol. Indeed, the mechanism of «guarantees of Origin» has some similarities with carbon quota and credit systems, since it provides for regulatory regulation of the market and financial incentives for participants implementing environmentally friendly generation. However, it differs in several key aspects: first, it provides confirmation of the actual consumption of «green» electricity, ensuring that the buyer receives energy produced from renewable sources; second, it helps to optimize the state's costs for supporting renewable energy sources, since the income from the sale of guarantees of origin received by the «guaranteed buyer» («Нарпок») is used to cover the costs of special obligations (PSO), reducing the financial burden on Ukrenergo; third, it ensures a fair distribution of benefits among market participants, fourth, it increases transparency and builds consumer confidence in the guarantee of origin market, and fifth, it encourages competition in the renewable energy sector [10].

However, despite the potential advantages of the mechanism of «guarantees of origin» of electricity, in practice its functioning in Ukraine remains incomplete [11]. Formally, the mechanism has been introduced, but the conditions for its real application, including an efficient market and an appropriate organizational and tech-

nic infrastructure, have not yet been created. This limits its ability to fulfil the stated tasks and stimulate the development of «green» generation. In particular, the lack of practical implementation of the key instrument – auctions – makes it impossible to create a transparent market for trading «guarantees of origin» and reduces the interest of investors and market participants in using this mechanism. As a result, instead of the expected stimulation of the development of renewable energy and assistance to the «green» transformation of electric power enterprises, we have a situation where the effectiveness of government decisions is called into question, since the market for «guarantees of origin» practically does not work, as evidenced by the results of numerous electronic auctions. The results of one of these auctions are presented in Table 1.

Table 1. Results of the electronic auction no. GO-010925 - 11 for the sale of guarantees of the origin of electric energy

Type	Declared sales volume	Sale
Seller	Guaranteed buyer, SE	Guaranteed buyer, SE
Energy source	Sun	Sun
Production period	September 2025	September 2024
Generating unit	not tied to the commissioning period	not tied to the commissioning period
Lots	10 000	0
Volume, GPEE (MWh)	10 000	0
Cost, excluding VAT	109 900.00	0
Starting price, excluding VAT	10,99	
Min. excluding VAT		0.00
Max. excluding VAT		0.00
Weighted average excluding VAT		0.00

Source: [12]

Thus, the results of the electronic auction No. GO-010925-11 for the sale of guarantees of the origin of electric energy are presented in Table.1, showed a complete lack of demand for the proposed resource. Despite the declared volume of 10,000 MWh. and the starting price of 10.99 UAH/MWh (excluding VAT), sales did not take place, which is confirmed by a zero result in all indicators [12]. This situation indicates a low interest of market participants in purchasing guarantees of origin, which is due to the lack of a clear regulatory framework, insufficient economic motivation or a low level of awareness of potential buyers. This, in turn, leads to criticism from stakeholders, who rightly emphasize the discrepancy between the declared goals of the state energy policy and the actual results of its implementation.

So, without removing organizational barriers and creating effective conditions for the functioning of the «guarantees of origin» market, The introduced mechanism risks remaining a nominal tool that does not fulfil its tasks in the context of the «green» transformation of electric power enterprises. To correct the situation, we

need both operational measures (analysis of causes, breakdown of lots, and simplification of procedures) and systematic steps (improvement of the regulatory framework, economic incentives, mechanisms for maintaining liquidity). Without such changes, the mechanism of «guarantees of origin» risks remaining nominal and does not contribute to the transition of electric power enterprises to low-carbon generation.

Taking into account the international experience in the development of renewable energy and the integration of digital technologies into financial and energy markets, we consider it relevant to introduce a tokenization mechanism for «guarantees of origin» in Ukraine. This approach involves the use of innovative tools of decentralized finance (DeFi), which make it possible to turn «guarantees of origin» of electricity into full-fledged digital assets. Each guarantee can be implemented in the form of a non-reciprocal token (NFT), which will ensure its uniqueness, liquidity and the ability to integrate into global digital markets.

A significant advantage in tokenizing «guarantees of origin» of electricity is the use of smart contracts that perform the function of automated transactions between market participants. They guarantee transparency, eliminate the possibility of manipulation, forgery or dual use of guarantees, and reduce transaction costs. Thanks to Blockchain Technologies, a permanent and open register of all transactions with «guarantees of origin» is

created. This creates a high level of trust between market participants, provides access to real-time transaction history, and creates additional control tools for regulators and consumers.

Consequently, in a broader context, tokenization of «guarantees of Origin» opens up the possibility of creating a new financial and ecological ecosystem. Producers of electricity from renewable sources will be able to monetize the «green» attributes of their products, which will stimulate investment activity in the sector and accelerate their further development. At the same time, businesses that exceed environmental regulations will be able to compensate for the negative impact on the environment by purchasing tokenized «guarantees of origin». In addition, the integration of «guarantees of origin» tokens into the sphere of digital assets will contribute to the development of secondary markets, where «guarantees of origin» can function as liquid instruments with their own market value. Such a transformation will provide an opportunity to attract additional financial resources to the industry, increase the transparency and competitiveness of the energy sector of Ukraine.

«Guarantee of origin» tokens should be issued on their own in the blockchain network, but subject to compliance with the following standards for their issue and circulation (Fig. 1).

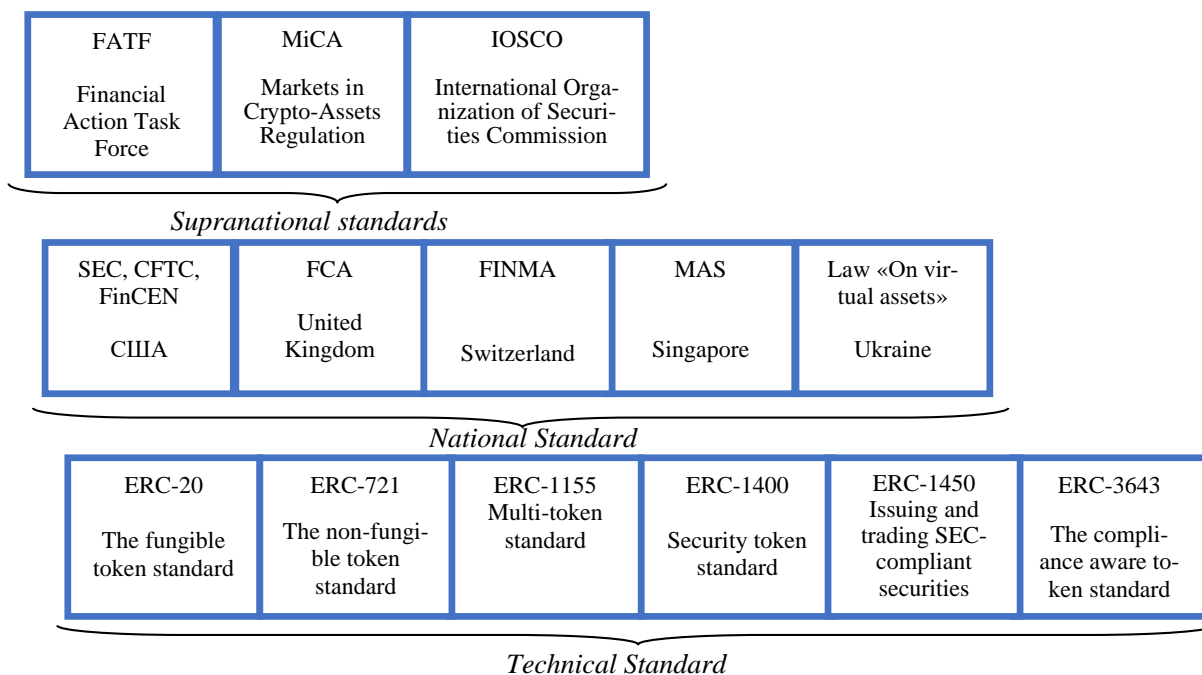


Fig. 1. Standards for regulating the issue and circulation of tokens

Source: [13-26]

«Guarantee of origin» tokens issued on their own directly in the blockchain network will exist exclusively in digital form from the moment of creation, that is, they will not require additional confirmation or conversion from paper or electronic certificates. This approach will

ensure maximum transparency and reliability, since all parameters of the guarantee of Origin (Energy source, production period, generation volume, and installation location) will be included in the smart contract at the token issue stage. The native release also eliminates the

risks of dual-use guarantees or database manipulation, because each transaction is displayed in a distributed ledger and is immutable. In addition, the integration of such an instrument into the financial infrastructure will open up opportunities for its further circulation in secondary markets, the formation of liquidity and price benchmarks. This will create prerequisites for the development of a full – fledged market ecosystem, in which producers of «green» energy receive a new source of funding, and consumers and investors-a tool for verifying and confirming environmental responsibility. Therefore, native tokenization of «guarantees of Origin» will

allow their purchase and sale on electronic platforms and secondary markets, forming a price benchmark and creating new investment opportunities for participants in the energy sector.

However, as noted earlier, native tokenization of «guarantees of origin» requires compliance with certain requirements and, above all, standards regarding token attributes. These attributes include unique identifiers that uniquely associate the token with a specific unit of electricity produced, information about the energy source, Generation period, and production volume (fig. 2).

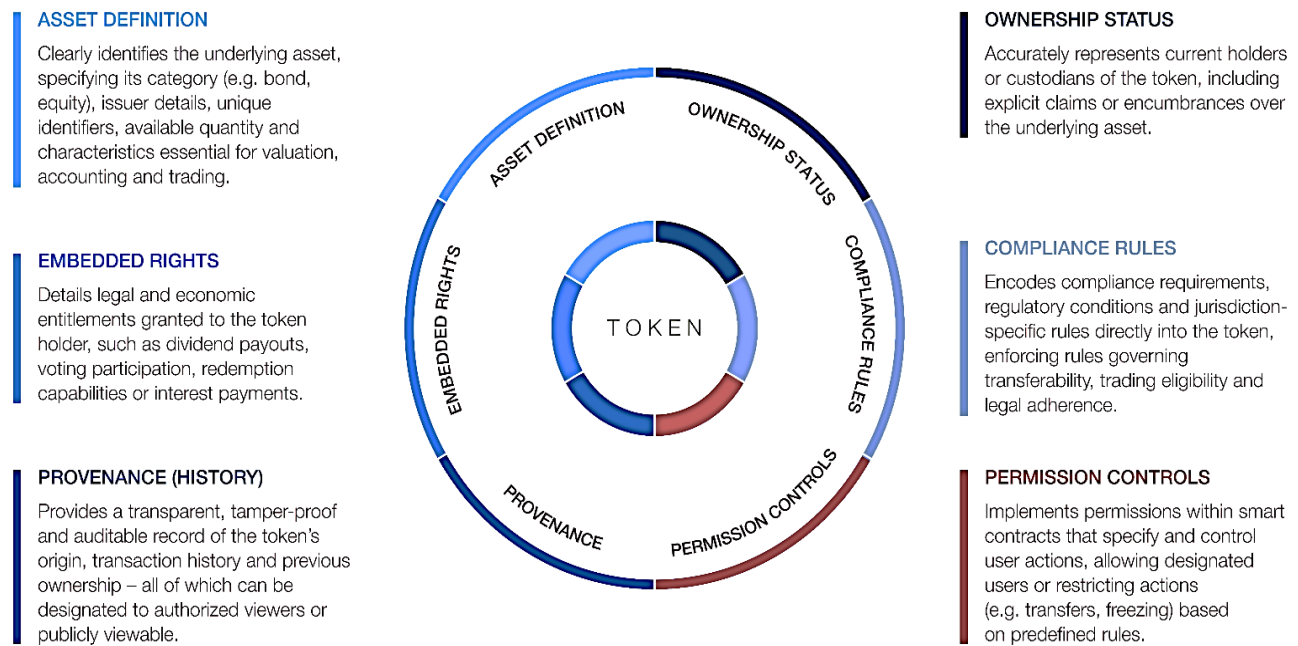


Fig. 2. Attributes of corporate asset tokens
Source: [27]

In addition, it is important to ensure the integration of the token into the blockchain network with support for smart contracts, which allows you to automate purchase and sale transactions, monitor the fulfilment of conditions and prevent double implementation of tokens.

Let's assume that enterprises that have reduced carbon emissions compared to the N_i regulatory level during the reporting period receive certificates of guarantee of origin (in the following amount):

$$S_i = \max(0, N_i - R_i). \quad (1)$$

These certificates can be tokenized and converted to digital assets using a coefficient k that determines the ratio between the certificate and the token :

$$T_i = kS_i. \quad (2)$$

The dynamics of token issuance may depend on the total volume of SOE certificates entering the system, as well as on market conditions. If the system is overloaded with an excess of tokens, the conversion k factor may be adaptive:

$$k = f(S_{3az}, X), \quad (3)$$

where $S_{3az} = \sum S_i$ - is the total number of certificates in the system;

X - is the total amount of excess emissions that need to be compensated.

Thus, the issue of tokens is a function of the actual reduction of emissions by energy companies and the adaptive conversion rate.

Let us assume that the demand for tokens is formed from enterprises that have exceeded their emission limits and need to compensate for them. If Enterprise j has excess emissions:

$$D_j = \max(0, R_j - N_j). \quad (4)$$

Then its need to purchase tokens will be:

$$T_j^{nomp} = \frac{D_j}{k}. \quad (5)$$

Total market demand is defined as the sum of the demand of all businesses:

$$D_{3az} = \sum_j D_j, \quad (6)$$

and, accordingly, the total required number of tokens to compensate for emissions:

$$T_{3az}^{nomp} = \frac{D_{3az}}{k}. \quad (7)$$

Therefore, demand for tokens of origin depends on a number of interrelated factors, including political, economic, technological and social aspects. Political and regulatory factors include the establishment of mandatory quotas for the use of green energy, tax incentives for companies that offset emissions, and penalties for exceeding environmental standards. These mechanisms encourage companies to actively engage in the token market, ensuring both demand and the formation of price benchmarks. Economic factors are determined by the financial capacity of polluting companies and their production activity. During periods of economic growth or high profitability, companies are more willing to invest in compensation mechanisms, while during periods of crisis, their capabilities are limited. Demand is also influenced by the existence of a secondary token market and the liquidity of assets: the more accessible and easier to trade tokens are, the higher the level of market participation.

Hence, the main vectors for ensuring the effectiveness of the electricity «guarantee of origin» mechanism should be recognised as follows:

- optimisation of the regulatory framework through the development of clear and transparent rules for the functioning of the «guarantees of origin» market, including accounting and reporting standards, which will ensure the trust of market participants and stimulate the active participation of green energy generators;

- the introduction of a blockchain-based technology platform, namely the use of smart contracts and digital tokens to automate the process of accounting, transfer and trading of «guarantees of origin», which increases transparency, protection against counterfeiting and transaction speed;

- development of a secondary market for digital assets by creating conditions for trading tokenised «guarantees of origin» between enterprises and investors, which will contribute to increasing asset liquidity and forming competitive market prices;

- introduction of government incentives and economic mechanisms through the implementation of tax breaks, subsidies and other incentives for enterprises that actively use green energy or offset their own emissions, as well as the application of penalties to encourage compliance with environmental standards;

- monitoring and evaluating effectiveness, regularly conducting analytical studies on the supply and demand for «guarantees of origin», the economic feasibility of tokenisation and the impact of the mechanism on the development of low-carbon generation, which will allow for timely adjustments to the strategy and improvement of the mechanism;

- Information support and awareness raising among market participants through training programmers, seminars and consultations for electricity producers and consumers on the benefits and principles of the tokenisation mechanism for «guarantees of origin»;

- integration with corporate ESG strategies by encouraging companies to include tokenised «guarantees of origin» for electricity in their sustainable development strategies and reporting on environmental, social and governance indicators, which will contribute to increased demand and confidence in the mechanism.

The implementation of these measures will create a more stable and predictable system for encouraging emissions reductions, increasing the investment attractiveness of renewable energy, and developing low-carbon electricity generation in the long term.

Conclusions.

The conducted research allowed us to comprehensively assess the effectiveness of the tokenization mechanism of «guarantees of origin» of electric energy and its impact on the development of «green» transformation of enterprises in the energy sector. The paper analyses in detail the conceptual and technological aspects of tokenization, including the use of blockchain technologies, smart contracts and digital assets in the form of non-reciprocal tokens. The key attributes of tokens that ensure their transparency, security, uniqueness and integration into the financial, economic and regulatory infrastructure of the market are identified, which creates conditions for reliable accounting, control and trading of «green» certificates.

The main factors that form the demand for «guarantee of origin» tokens are analysed. Among them, political and regulatory incentives are highlighted, including the establishment of mandatory quotas for the use of «green» energy, tax incentives for enterprises that compensate for their own emissions, as well as the application of penalties for exceeding environmental standards. It is proved that the economic activity of polluting enterprises directly affects the willingness to invest in tokens: during periods of production growth and increased profitability, companies have more resources to participate in emission compensation mechanisms, while in times of crisis their financial capabilities are limited. It is emphasized that the development of the secondary market of digital assets provides an increase in the liquidity of tokens, the formation of market prices and the creation of conditions for a transparent and efficient financial and ecological ecosystem, stimulating the further development of low-carbon electricity generation and the integration of renewable sources into the national energy system.

So, tokenization of «guarantees of origin» of electricity is a promising tool for decarbonizing the energy sector, increasing the liquidity of «green» assets, creating transparent market mechanisms and ensuring a balance between environmental goals, economic feasibility and the interests of all market participants.

LITERATURE

1. Клімович С. В. Переваги та недоліки токенизації підприємств. *Науковий вісник Ужгородського національного університету. Серія: Міжнародні економічні відносини та світове господарство*. 2024. Вип. 52. С. 97-102. URL: http://www.visnyk-econom.uzhnu.uz.ua/archive/52_2024ua/17.pdf
2. Череп О., Дашко Я., Михайліченко Л. Криптогоризонт: цифровий ключ до інвестиційного майбутнього. *Вісник Хмельницького національного університету. Серія: Економічні науки*. 2025. Т. 344, № 4. С. 209-215. <https://doi.org/10.31891/2307-5740-2025-344-4-28>
3. Будник В. Суть цифрових активів: концептуальні основи та сучасний контекст. *Вісник Економіки*. 2025. № 1. Р. 148-160. <https://doi.org/10.35774/visnyk2025.01.148>
4. Федоренко І. Трансформації в економічних відносинах, на які вплинуло впровадження токенизованих активів. *Економічний аналіз*. 2023. Т. 33, № 3. С. 178-189. <https://doi.org/10.35774/econ2023.03.178>
5. Миронов О. Г. Розвиток віртуальної економіки через впровадження токенизованих активів у реальні галі економіки. *Академічні візії*. 2024. № 38. <https://doi.org/10.5281/zenodo.14534556>
6. Перебийніс Д. С. Токенизовані активи та їх роль у модернізації традиційних методів залучення капіталу. *Інвестиції: практика та досвід*. 2025. № 5. С. 210-216. <https://doi.org/10.32702/2306-6814.2025.5.210>
7. Перебийніс Д. С. Як електронні фінансові технології змінюють підходи до залучення капіталу. *Modern Economics*. 2025. № 49 (2025). С. 177-187. [https://doi.org/10.31521/modecon.V49\(2025\)-24](https://doi.org/10.31521/modecon.V49(2025)-24)
8. Про внесення змін до деяких законів України щодо відновлення та «зеленої» трансформації енергетичної системи України: Закон України від 30 червня 2023 року за № 3220-ІХ. URL: <https://zakon.rada.gov.ua/laws/show/3220-20#Text>
9. Levchenko S. Debt crisis in the electricity market: causes and threats to the. *Економічний вісник Державного вищого навчального закладу «Український державний хіміко-технологічний університет»*. 2023. № 2. С. 85-92. <https://doi.org/10.32434/2415-3974-2023-18-2-85-92>
10. Лоза С. П., Братковська К. О. Ринок гарантій походження електроенергії та його вплив на економічну безпеку підприємств електроенергетики. *Актуальні питання економічних наук*. 2024. №5. <https://doi.org/10.5281/zenodo.15107133>
11. Левченко Н. М., Антонова Л. В. Державне регулювання процесу трансформації енергетики від застарілої моделі її функціонування до новітньої «низьковуглецевої» моделі. *Public Administration and Regional Development*. 2020. № 10 (1). С. 1247-1263. <https://doi.org/10.34132/pard2020.10.12>
12. Календар торгів: Гарантії походження електроенергії. URL: <https://www.ueex.com.ua/auctions-calendar/garantii-pohodzhennya-elektroenergii/?y=2025&m=02>
13. CFTC, FinCEN. *U.S. Securities and Exchange Commission*. 2019. URL: <https://www.sec.gov/newsroom/speeches-statements/cftc-fincen-sec-jointstatementdigitalassets>
14. ERC-1155. Multi-token standard. *Ethereum Improvement Proposals*. 2018. URL: <https://docs.openzeppelin.com/contracts/3.x/erc1155>
15. ERC-1400. Security token standard. *Ethereum Improvement Proposals*. 2018. URL: <https://github.com/ethereum/EIPs/issues/1411>
16. ERC-1410. Partially Fungible Token Standard. *Ethereum Improvement Proposals*. 2018. URL: <https://github.com/ethereum/EIPs/issues/1410>
17. ERC-1450. A compatible security token for issuing and trading SEC-compliant securities. *Ethereum Improvement Proposals*. 2018. URL: <https://eips.ethereum.org/EIPS/eip-1450>
18. ERC-20. The fungible token standard. *Base.docs*. 2015. URL: <https://docs.base.org/learn/token-development/erc-20-token/erc-20-standard>
19. ERC-3643. The compliance aware token standard. *Tokeny*. 2021. URL: <https://tokeny.com/erc3643/>
20. ERC-721. The non-fungible token standard. *Ethereum Foundation*. 2018. URL: <https://ethereum.org/uk/developers/docs/standards/tokens/erc-721/>
21. Targeted Update on Implementation of the FATF Standards on Virtual Assets and Virtual Asset Service Providers. *Financial Action Task Force (FATF)*. 2025. URL: <https://www.fatf-gafi.org/content/dam/fatf-gafi/recommendations/2025-Targeted-Udate-VA-VASPs.pdf.coredownload.pdf>
22. Industry Codes of Conduct and Feedback on FCA Principle 5. *FCA*. 2018. URL: <https://www.fca.org.uk/publication/policy/ps18-18.pdf>
23. Registerharmonisierungsverordnung. 431.021 (RHV). (Stand am 2025, June 1). *FINMA*. URL: <https://www.fedlex.admin.ch/eli/cc/2024/141/de>
24. International Organization of Securities Commission. *IOSCO*. 2024. URL: <https://www.iosco.org/>
25. Markets in Crypto-Assets Regulation. (2023). *ESMA*. URL: <https://www.esma.europa.eu/esmas-activities/digital-finance-and-innovation/markets-crypto-assets-regulation-mica>
26. Securities and Futures Act. *MAS*. 2001. URL: <https://sso.agc.gov.sg/act/sfa2001>
27. Asset Tokenization in Financial Markets: The Next Generation of Value Exchange. Insight report. *World Economic Forum*. 2025. URL: https://reports.weforum.org/docs/WEF_Asset_Tokenization_in_Financial_Markets_2025.pdf

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REFERENCES

1. Klimovych, S. V. (2024). Advantages and disadvantages of enterprise tokenization. *Scientific Bulletin of Uzhhorod National University. Series: International Economic Relations and the World Economy*, 52, 97–102. http://www.visnyk-econom.uzhnu.uz.ua/archive/52_2024ua/17.pdf [in Ukrainian].

2. Cherep, O., Dashko, I., & Mykhailichenko, L. (2025). Crypto horizon: A digital key to the investment future. *Bulletin of Khmelnytskyi National University. Series: Economic Sciences*, 344(4), 209–215. <https://doi.org/10.31891/2307-5740-2025-344-4-28> [in Ukrainian].
3. Budnyk, V. (2025). The essence of digital assets: Conceptual foundations and modern context. *Visnyk Ekonomiky*, 1, 148–160. <https://doi.org/10.35774/visnyk2025.01.148> [in Ukrainian].
4. Fedorenko, I. (2023). Transformations in economic relations influenced by the introduction of tokenized assets. *Economic Analysis*, 33(3), 178–189. <https://doi.org/10.35774/econa2023.03.178> [in Ukrainian].
5. Myronov, O. H. (2024). Development of the virtual economy through the implementation of tokenized assets in real economic sectors. *Academic Visions*, 38. <https://doi.org/10.5281/zenodo.14534556> [in Ukrainian].
6. Perebiinis, D. S. (2025). Tokenized assets and their role in modernizing traditional methods of raising capital. *Investments: Practice and Experience*, 5, 210–216. <https://doi.org/10.32702/2306-6814.2025.5.210> [in Ukrainian].
7. Perebiinis, D. S. (2025). How electronic financial technologies are changing approaches to raising capital. *Modern Economics*, 49, 177–187. [https://doi.org/10.31521/modecon.V49\(2025\)-24](https://doi.org/10.31521/modecon.V49(2025)-24) [in Ukrainian].
8. Verkhovna Rada of Ukraine. (2023, June 30). On amendments to certain laws of Ukraine regarding the recovery and «green» transformation of the energy system of Ukraine: Law of Ukraine No. 3220-IX. URL: <https://zakon.rada.gov.ua/laws/show/3220-20#Text> [in Ukrainian].
9. Levchenko, S. (2023). Debt crisis in the electricity market: Causes and threats. *Economic Bulletin of the Ukrainian State University of Chemical Technology*, 2, 85–92. <https://doi.org/10.32434/2415-3974-2023-18-2-85-92> [in Ukrainian].
10. Loza, S. P., & Bratkovska, K. O. (2024). The market of guarantees of origin of electricity and its impact on the economic security of energy enterprises. *Current Issues of Economic Sciences*, 5. URL: <https://doi.org/10.5281/zenodo.15107133> [in Ukrainian].
11. Levchenko, N. M., & Antonova, L. V. (2020). State regulation of the transformation of energy from an outdated model to a modern «low-carbon» model. *Public Administration and Regional Development*, 10(1), 1247–1263. <https://doi.org/10.34132/pard2020.10.12> [in Ukrainian].
12. Ukrainian Energy Exchange. (2025). Auction calendar: Guarantees of origin of electricity. URL: <https://www.ueex.com.ua/auctions-calendar/garantii-pohodzhennya-elektroenergii/?y=2025&m=02> [in Ukrainian].
13. CFTC, FinCEN, & U.S. Securities and Exchange Commission. (2019). Joint statement on digital assets. URL: <https://www.sec.gov/newsroom/speeches-statements/cftc-fincen-sec-jointstatementdigitalassets>
14. Ethereum Improvement Proposals. (2018). ERC-1155: Multi-token standard. URL: <https://docs.openzeppelin.com/contracts/3.x/erc1155>
15. Ethereum Improvement Proposals. (2018). ERC-1400: Security token standard. URL: <https://github.com/ethereum/EIPs/issues/1411>
16. Ethereum Improvement Proposals. (2018). ERC-1410: Partially fungible token standard. URL: <https://github.com/ethereum/EIPs/issues/1410>
17. Ethereum Improvement Proposals. (2018). ERC-1450: A compatible security token for issuing and trading SEC-compliant securities. URL: <https://eips.ethereum.org/EIPS/eip-1450>
18. Base Docs. (2015). ERC-20: The fungible token standard. URL: <https://docs.base.org/learn/token-development/erc-20-token/erc-20-standard>
19. Tokeny. (2021). ERC-3643: The compliance-aware token standard. URL: <https://tokeny.com/erc3643/>
20. Ethereum Foundation. (2018). ERC-721: The non-fungible token standard. URL: <https://ethereum.org/uk/developers/docs/standards/tokens/erc-721/>
21. Financial Action Task Force (FATF). (2025). Targeted update on implementation of the FATF standards on virtual assets and virtual asset service providers. URL: <https://www.fatf-gafi.org/content/dam/fatf-gafi/recommendations/2025-Targeted-Update-VA-VASPs.pdf.coredownload.pdf>
22. Financial Conduct Authority (FCA). (2018). Industry codes of conduct and feedback on FCA Principle 5. URL: <https://www.fca.org.uk/publication/policy/ps18-18.pdf>
23. FINMA. (2025). Registerharmonisierungsverordnung. 431.021 (RHV). URL: <https://www.fedlex.admin.ch/eli/cc/2024/141/de>
24. International Organization of Securities Commissions (IOSCO). (2024). URL: <https://www.iosco.org/>
25. European Securities and Markets Authority (ESMA). (2023). Markets in Crypto-Assets Regulation (MiCA). URL: <https://www.esma.europa.eu/esmas-activities/digital-finance-and-innovation/markets-crypto-assets-regulation-mica>
26. Monetary Authority of Singapore (MAS). (2001). Securities and Futures Act. URL: <https://sso.agc.gov.sg/act/sfa2001>
27. World Economic Forum. (2025). Asset tokenization in financial markets: The next generation of value exchange (Insight report). URL: https://reports.weforum.org/docs/WEF_Asset_Tokenization_in_Financial_Markets_2025.pdf

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Levchenko N., Levchenko S. Analysis of the effectiveness of the tokenisation mechanism of «Guarantees of Origin» for electricity and its impact on the «green» transformation of electric power companies

The article presents a comprehensive analysis of the efficiency of the mechanism for tokenizing Guarantees of Origin (GoO) of electricity and its impact on the development of the «green» transformation of energy sector enterprises. The conceptual and technological aspects of tokenization have been examined, including the application of blockchain technologies, smart contracts, and digital assets in the form of non-fungible tokens (NFTs). Particular attention has been paid to identifying the key attributes of tokens that ensure their transparency, security, and uniqueness, as well as to the integration of the tokenization mechanism into the financial, economic, and regulatory infrastructure of the energy market.

The main factors shaping the demand for GoO tokens have been analyzed, among which the most significant are political regulations and state incentives, including the establishment of mandatory quotas for the use of «green» energy, the provision of tax benefits for enterprises compensating their emissions, and the imposition of penalties for exceeding environmental standards. An assessment of the economic feasibility of tokenization, potential risks, and possible benefits for producers of «green» electricity, consumers, and

investors has been carried out. It has been determined that the economic activity of polluting enterprises directly affects their willingness to invest in tokens, since during periods of increased production and profitability, enterprises have more resources to participate in emission compensation mechanisms, whereas in crisis periods their financial capacities are limited. The development of a secondary market for digital assets contributes to token liquidity, the formation of market prices, and the creation of conditions for the effective functioning of a financial-ecological ecosystem, thereby promoting the further development of low-carbon electricity generation.

Based on the results of the study, conclusions have been drawn regarding the role of tokenization as a tool for stimulating decarbonization, enhancing the liquidity of «green» assets, and creating a transparent financial-ecological ecosystem. Recommendations have been formulated for optimizing the GoO tokenization mechanism, improving its efficiency, and promoting the development of the low-carbon energy sector, ensuring a balance between environmental objectives, economic feasibility, and the interests of market participants.

Keywords: Guarantees of Origin, tokenization mechanism, tokenization efficiency, green transformation, blockchain, GoO liquidity, demand for Guarantees of Origin, environmental value, low-carbon electricity generation.

Левченко Н. М., Левченко С. А. Аналіз ефективності механізму токенизації «гарантій походження» електричної енергії та його впливу на «зелену» трансформацію підприємств електроенергетики

У статті здійснено комплексний аналіз ефективності механізму токенизації «гарантій походження» електричної енергії та його впливу на розвиток «зеленої» трансформації підприємств енергетичного сектору. Досліджено концептуальні та технологічні аспекти токенизації, включаючи застосування блокчейн-технологій, смарт-контрактів і цифрових активів у формі невзаємозамінних токенів. Особлива увага приділена визначенню ключових атрибутів токенів, що забезпечують їх прозорість, безпеку та унікальність, а також інтеграції механізму токенизації у фінансово-економічну та регуляторну інфраструктуру енергетичного ринку. Проаналізовано основні фактори, що формують попит на токени «гарантій походження», серед яких ключовими визнано політичне регулювання та державні стимули, що включають встановлення обов'язкових квот на використання «зеленої» енергії, надання податкових пільг для підприємств, які компенсують власні викиди, та застосування штрафних санкцій за перевищення екологічних нормативів. Проведено оцінку економічної доцільності токенизації, можливих ризиків та потенційних вигод для виробників «зеленої» електроенергії, споживачів та інвесторів. Встановлено, що економічна активність підприємств-забруднювачів безпосередньо впливає на готовність інвестувати у токени, адже у періоди зростання виробництва та прибутковості підприємства мають більше ресурсів для участі у механізмах компенсації викидів, тоді як у кризові періоди їхні фінансові можливості обмежені. Обґрунтовано, що розвиток вторинного ринку цифрових активів сприяє ліквідності токенів, формуванню ринкових цін та створенню умов для ефективного функціонування фінансово-екологічної екосистеми, стимулюючи подальший розвиток низьковуглецевої генерації електроенергії. Сформульовано на основі результатів дослідження висновки щодо ролі токенизації як інструмента стимулювання декарбонізації, підвищення ліквідності «зелених» активів і створення прозорої фінансово-екологічної екосистеми. Сформовано рекомендації щодо оптимізації механізму токенизації «гарантій походження», підвищення його ефективності та сприяння розвитку низьковуглецевого енергетичного сектору, здатних забезпечити баланс між екологічними цілями, економічною доцільністю та інтересами учасників ринку електроенергії.

Ключові слова: «гарантій походження», механізм токенизації, ефективність механізму токенизації, «зелена» трансформація, блокчейн, ліквідність «гарантій походження», попит на «гарантій походження», екологічна цінність, низьковуглецева генерація електроенергії.