

# Dynamics of tax revenue growth in ensuring regional development using machine learning\*

Oksana Desyatnyuk<sup>1,†</sup>, Fedir Tkachyk<sup>1,†</sup>, Svitlana Sachenko<sup>1,\*†</sup>, Danylo Severynenko<sup>2,†</sup> and Iryna Novosad<sup>1,†</sup>

<sup>1</sup> West Ukrainian National University, Lvivska Str. 11, 46009, Ternopil, Ukraine

<sup>2</sup> Lviv Polytechnic National University, Bandera Str. 12, 79012, Lviv, Ukraine

## Abstract

A goal of this paper is to examine the essence and role of tax revenues in the formation of financial resources of local budgets using modern information technologies to ensure the effective development of regions in Ukraine. Modern trends in the formation of state and local budget revenues in Ukraine were analyzed, as a result of which the dominant fiscal role of tax payments was established. On the basis of machine learning technologies, the dynamics of indicators of the increase in tax revenues of local budgets in the regions of Ukraine were determined, on the basis of which their clustering was carried out. It has been established that under the legal regime of martial law in Ukraine, the regions that have suffered the most from hostilities need alternative sources of the financial support. Because the local governments cannot fully ensure the process of effective administration of taxes and fees. Such a context requires effective management decisions and measures to ensure the sustainable development of Ukraine's regions in the near future.

## Keywords

Fiscal policy, budget system, tax revenue, local budgets, regional development, machine learning, programming language Python, Matplotlib, Seaborn

## 1. Introduction and related works

To perform its functions, the state must have a sufficient financial base. In Ukraine, there is a problem of forming an adequate amount of revenues of the state and local budgets. Budget revenues are the basis of the system of financial support for the socio-economic development of the country and occupy an important place in the formation of the state's budgetary resources. As a result, the task arises to find the most effective methods of forming budgetary resources of the state and regions at the expense of tax payments.

Even Adam Smith considered taxes an objective necessity, as they are determined by the needs of the progressive development of society [1]. Tax revenues are formed due to the accumulation of taxes, fees and mandatory payments to the budget, which together form the taxation system in the structure of state finances [2-4]. At the same time, the formation of tax revenues of the local budgets is a process of initiation, administration and accumulation of taxes using the tools of fiscal pressure [18] taking into account the key principles of financial decentralization [5] and tax ethics [6]. Nevertheless, in our opinion, the main purpose of tax revenues is manifested through their elements in the context of providing the state and territorial communities with financial resources necessary for the performance of priority functions.

---

*AdvAIT-2024: 1st International Workshop on Advanced Applied Information Technologies, December 5, 2024, Khmelnytskyi, Ukraine - Zilina, Slovakia*

\* Corresponding author.

† These authors contributed equally.

✉ rektor@wunu.edu.ua (O. Desyatnyuk); tkachyk.fp@gmail.com (F. Tkachyk); s\_sachenko@yahoo.com (S. Sachenko); danylo.y.severynenko@lpnu.ua (D. Severynenko);

ORCID 0000-0002-1384-4240 (O. Desyatnyuk); 0000-0002-4783-6919 (F. Tkachyk); 0000-0001-8225-1820 (S. Sachenko); 0000-0002-1708-316X (D. Severynenko);



© 2024 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

Thus, understanding the composition and dynamics of tax revenues at the levels of the budget system is extremely important in the context of their analysis and planning, the identification of growth reserves [7, 29] for making optimal decisions regarding the directions of fiscal policy reform [12] and ensuring the sustainable development of Ukraine and its territorial communities [11] with using modern information technologies.

Along with this, the general factors that influence the growth of tax revenues to the budgets of all levels are the periodic effective detinization of the economy, the stimulation of business entities [28], the use of modern information and communication technologies in taxation, the delegation of fiscal powers to local self-government bodies. This one can better control the payment of tax payments and mandatory fees in the territorial plane, as well as optimal use of the resource potential of regions for financial and environmental purposes [30].

Local budgets, with the help of taxes and fees, actively influence the economic and social processes of administrative-territorial units and create opportunities for solving the problems of effective regional development and improving the quality of life of citizens [8, 10]. However, the optimal formation and use of tax resources of local budgets should be determined on the basis of priorities and strategic goals of the development of the state and territorial communities. Diversification of types of taxes provided territorial communities with an appropriate level of resistance to long-term economic changes and constant crises [14, 20]. To date, the war started by the Russian Federation in Ukraine has created additional risks for the financial stability of state and local budgets, and has become an important factor affecting the competitiveness of the country's territories.

Therefore, the question of the effectiveness of tax collection for local budgets and finding ways to increase the fiscal potential in terms of the dynamics of its key dominants is relevant for our state and attracts the attention of scientists and practitioners [21, 24].

In [28], an attempt was made to analyze the dynamics of taxes and fees in the revenues of local budgets of Ukraine. However, such an approach to the analysis of the dynamics of taxes and fees requires considerable time and human resources. In our opinion, an important factor is the digitization of tax relations and the use of artificial intelligence technologies [22, 26], in particular machine learning [13, 15, 16]. Moreover, it increases the efficiency of tax collection and settlement and reduces corruption risks, as direct contact between government officials and taxpayers is minimized. That is why we propose to implement the monitoring of local budget revenue generation indicators with the help of machine learning, which is shown below.

## **2. Methods and materials**

A preliminary analysis of the revenues for the state and local budgets of Ukraine from various sources [9, 25, 27] over the past 8 years confirmed their significant impact on competitiveness and financial independence of local self-government, building up the fiscal potential of the state and territorial communities.

On the basis of statistical methods and data grouping, information on the state of financing the needs of territorial communities from various sources was systematized according to the budget classification. The information base of the study was official public data on the receipt of tax and other payments to budgets of all levels [17]. Matplotlib – a Python package for graphical display of tax revenue dynamics and clustering of regions – was employed.

The processing of a data set on the receipt of taxes and fees to local budgets in Ukraine with the help of machine learning served as the basis for the clustering of regions in order to identify those with low tax potential and develop recommendations for increasing the fiscal efficiency of tax payments in the context of ensuring economic growth in the regions of Ukraine.

### 3. Case study and results

The study of the specific weight of tax revenues in the structure of state and local budgets made it possible to reveal their fiscal role in the context of ensuring the tasks of socio-economic development of Ukraine. The empirical approach proved a certain unstable trend in the process of formation of budget resources in Ukraine at the expense of taxes and fees in 2018-2023 (Table 1) [17]. In particular, a significant increase was found in 2023 – 2.9 times compared to the previous reporting year. In addition, it should be noted the colossal increase in revenues from the European Union, foreign governments, and international organizations in 2022 - 370 times.

**Table 1**

Financial resources of state and local budgets in Ukraine for 2018-2023, UAH billion

Income categories	State budget						Local budget					
	2018	2019	2020	2021	2022	2023	2018	2019	2020	2021	2022	2023
Tax revenues	753.82	799.78	851.12	1107.09	949.76	1203.54	232.53	270.55	285.57	346.71	393.46	434.54
Non-tax revenues	164,68	186,68	212,95	175,36	346,33	991,6	28,03	26,11	21,46	27,18	22,04	36,51
Income from capital transactions	0,65	0,18	0,79	0,33	0,61	0,1	2,14	2,93	3,47	3,46	2,28	3,62
From state administration bodies	7,31	8,73	10,65	12,58	9,47	42,92	298,94	260,3	160,18	202,73	136,75	177,39
From the EU, foreign governments, international organizations	1,46	1,14	1,03	1,29	481,09	433,4	0,09	0,04	0,15	0,04	0,22	0,2
Trust funds	0,19	1,77	0,19	0,21	0,14	0,43	0,68	0,6	0,65	0,57	0,34	0,35
<b>Total</b>	<b>928,11</b>	<b>998,28</b>	<b>1076,02</b>	<b>1296,85</b>	<b>1787,39</b>	<b>2671,99</b>	<b>562,42</b>	<b>560,53</b>	<b>471,48</b>	<b>580,69</b>	<b>555,09</b>	<b>652,61</b>

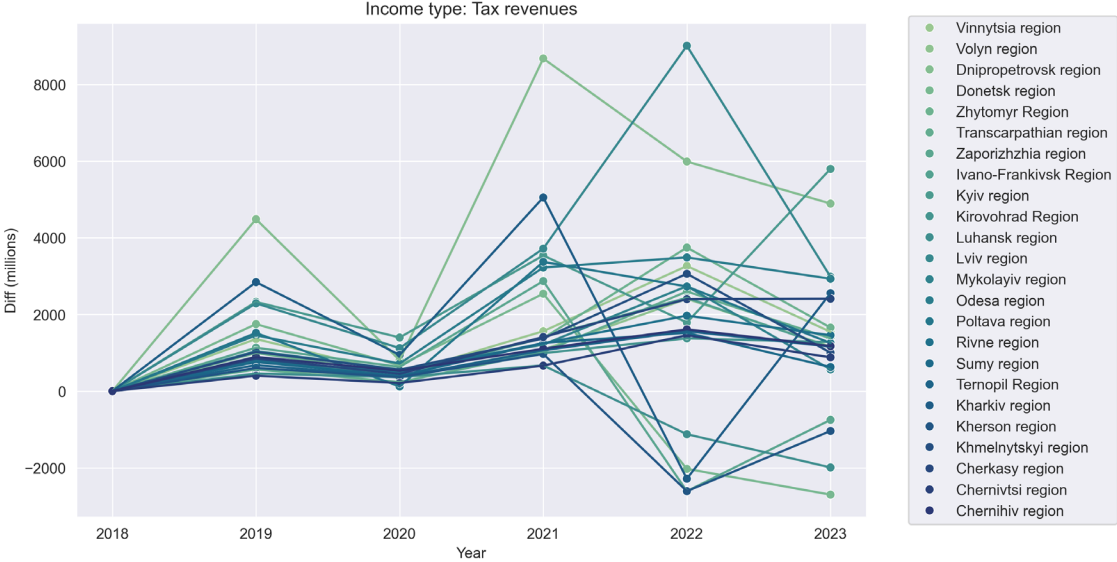
On the basis of machine learning methods, general indicators of the growth of local budget revenues in dynamics for 2018-2023 were obtained (Fig. 1).



**Figure 1:** Dynamics of growth indicators of local budget revenues by region of Ukraine in 2018-2023, million UAH.

As can be seen from fig. 1, that the level of implementation of local budgets by income with the start of a full-scale war in 2022. directly depended on the state of hostilities in the regions. The increase compared to the previous year and the implementation of the planned indicators of the general fund revenues according to the consolidated budgets of the regions were not ensured: Donetsk region - UAH 2.9 billion, Zaporizhia region - UAH 3.7 billion, Luhansk region - UAH 2.0 billion, Kharkiv region - UAH 3.1 billion , Khersonska – UAH 2.9 billion. At the same time, in certain regions (Lviv, Zhytomyr, Zakarpattia, Volyn, Khmelnytskyi, Chernivtsi, Ivano-Frankivsk) the increase in revenues of the general fund amounted to more than 30%

During the considered period, there is a significant increase in the share of tax revenues in the structure of state and local budget revenues. For example, in 2018, the share of tax payments in the total revenues of local budgets was 41.34%, while in 2022 this indicator increased to 70.88%, and in 2023 it was 66.58%. The revealed dynamics prove the moderate success of the implementation of tax reforms and the positive impact of these changes on the financial stability and independence of local budgets, despite the general macroeconomic instability [23]. In other areas, the dynamics were characterized by a positive aspect, which can be observed in fig. 2.



**Figure 2:** Dynamics of tax revenue growth indicators in the structure of local budgets in Ukraine.

As can be seen from Fig. 2, the indicators of tax revenues and fees regionally show significant differences depending on the region. Thus, regions where the population increased due to migration processes and business relocation showed a significant increase in budget resources. On the other hand, in other regions, in particular those that have experienced a significant destructive impact as a result of military aggression, such a high increase is not observed, but on the contrary, the negative dynamics of this type of income is observed.

With the help of machine learning technologies, the regions of Ukraine were clustered according to the indicator of accumulation of tax revenues in 2018-2023. For this purpose, the peculiarities of the functioning of tools for intellectual data analysis, which are generally divided into three types, were investigated: 1) programming languages 2) statistical tools 3) tools visualization. This became the basis for choosing the programming language - Python in the process of visualizing data on tax revenues in a regional section for grouping the regions of Ukraine according to this parameter. Python is a powerful, high-level, versatile and resource-intensive programming language. Matplotlib is one of the most popular Python data visualization libraries. This library was created by J. Hunter along with several contributors and she spent more time hinting this software that is used by all scientists and philosophers around the world. Seaborn is a graphical rendering library built on top of Matplotlib's core configurations.

Matplotlib is the most common library for creating static, animated and interactive graphs in Python. The Matplotlib package is similar in structure to NumPy, SciPy, and IPython and provides similar capabilities to the MATLAB package. The package currently works with several graphics libraries, including wxWindows and PyGTK [19].

The obtained histograms of the visualization of the distribution of numerical data according to the parameters of tax revenues to the local budgets of Ukraine - the clustering of regions according to the level of tax revenues (Fig. 3-8). As a result, three cluster groups were formed according to the following parameters:

- Group 1 – the amount of tax revenues to local budgets in the range of up to UAH 10 billion;
- Group 2 – the amount of tax revenues to local budgets in the range from UAH 10 billion to UAH 15 billion;
- Group 3 – the amount of tax revenues to local budgets in the range of UAH 15 billion or more.

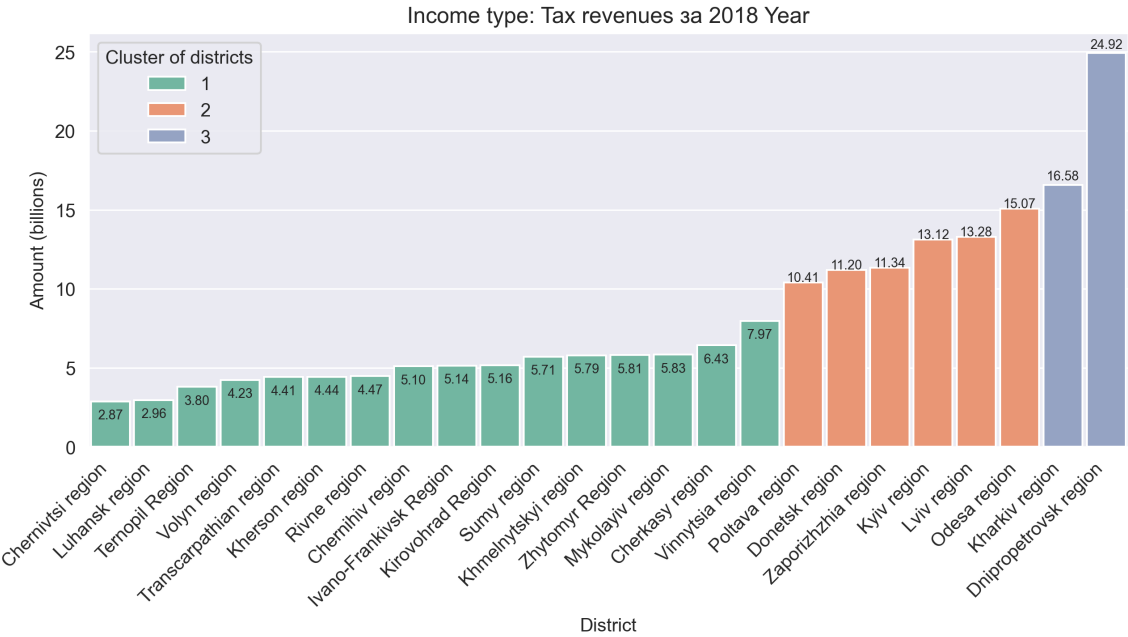


Figure 3: Clustering of regions by tax revenues of local budgets of Ukraine in 2018, billion UAH.

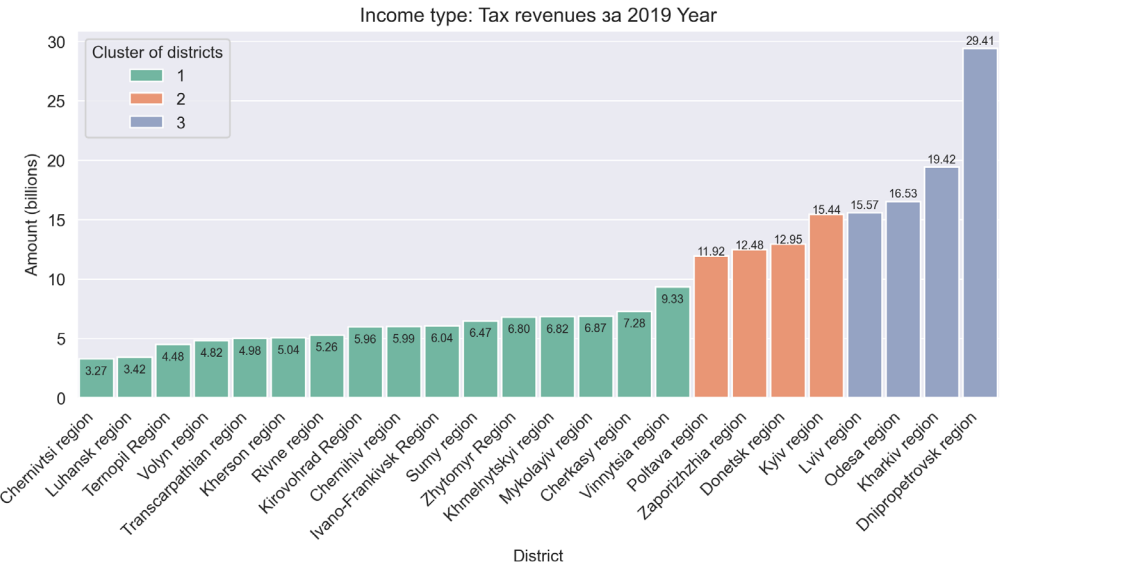
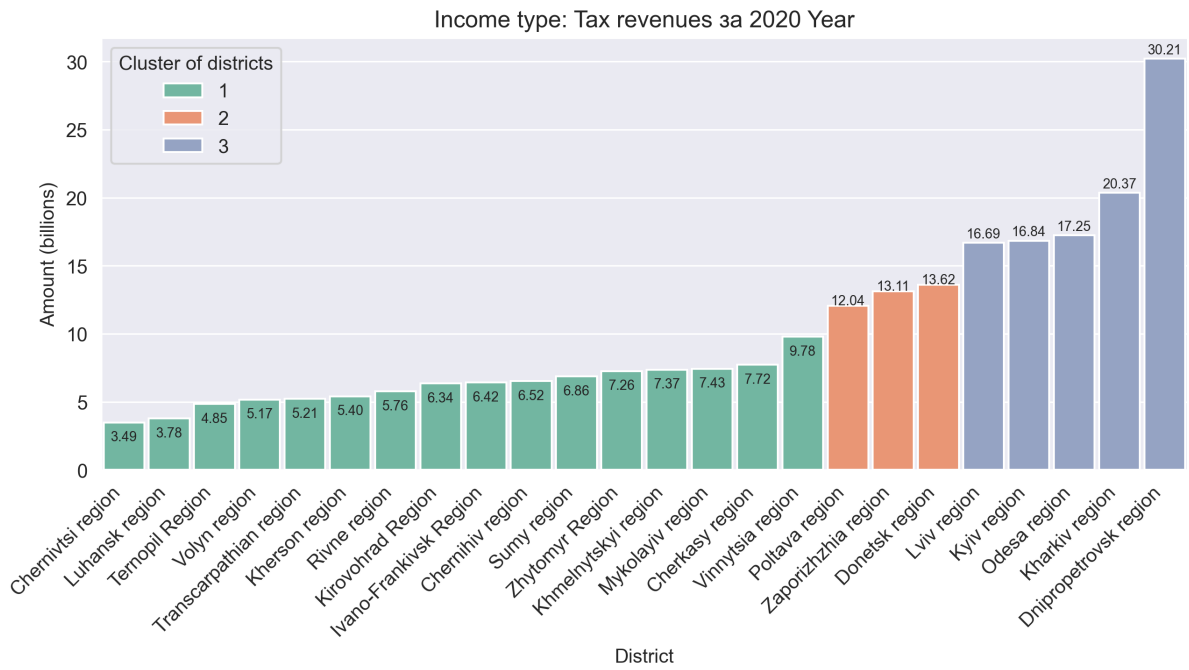
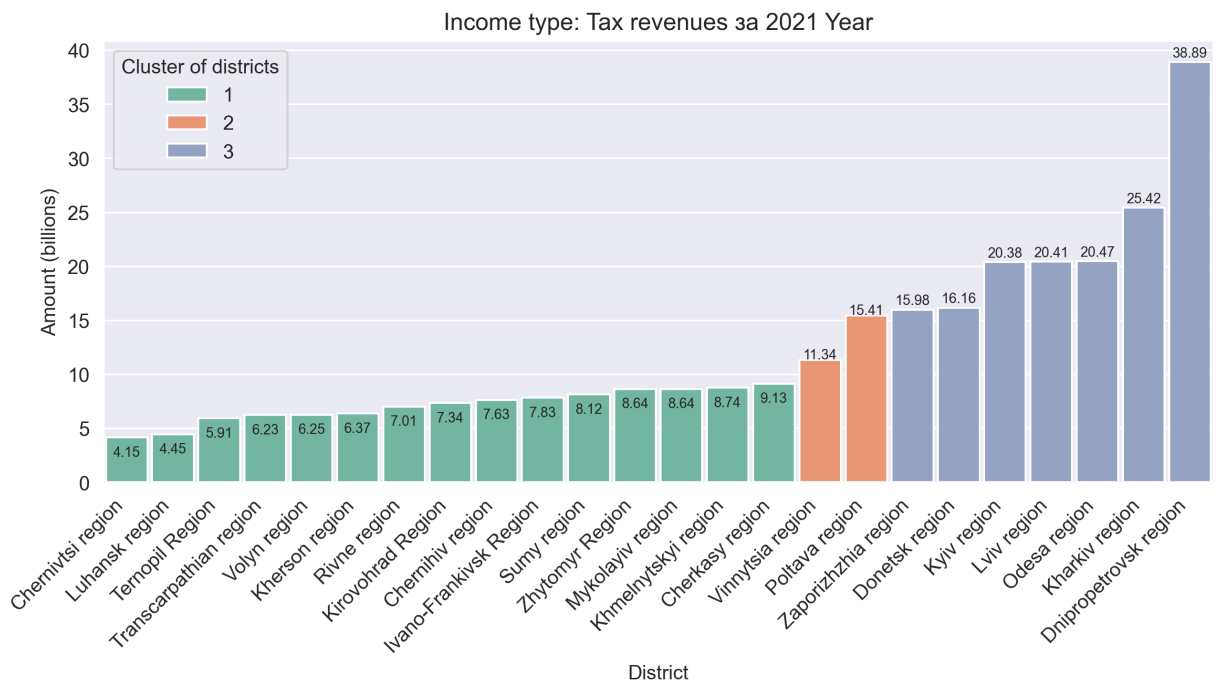


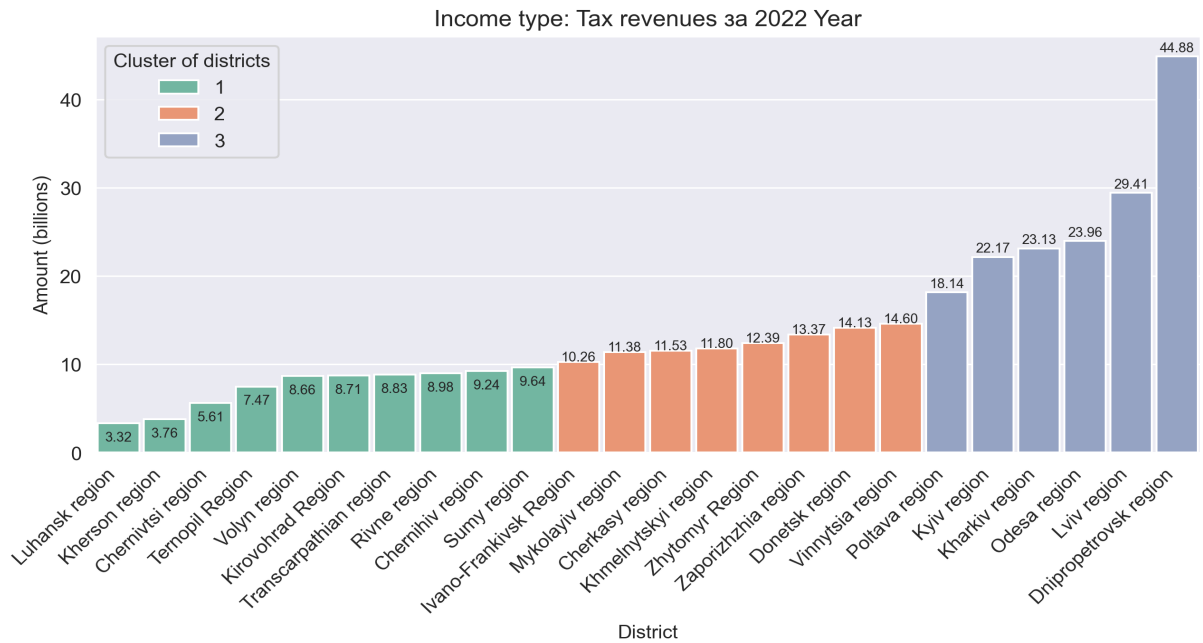
Figure 4: Clustering of regions by tax revenues of local budgets of Ukraine in 2019, billion UAH.



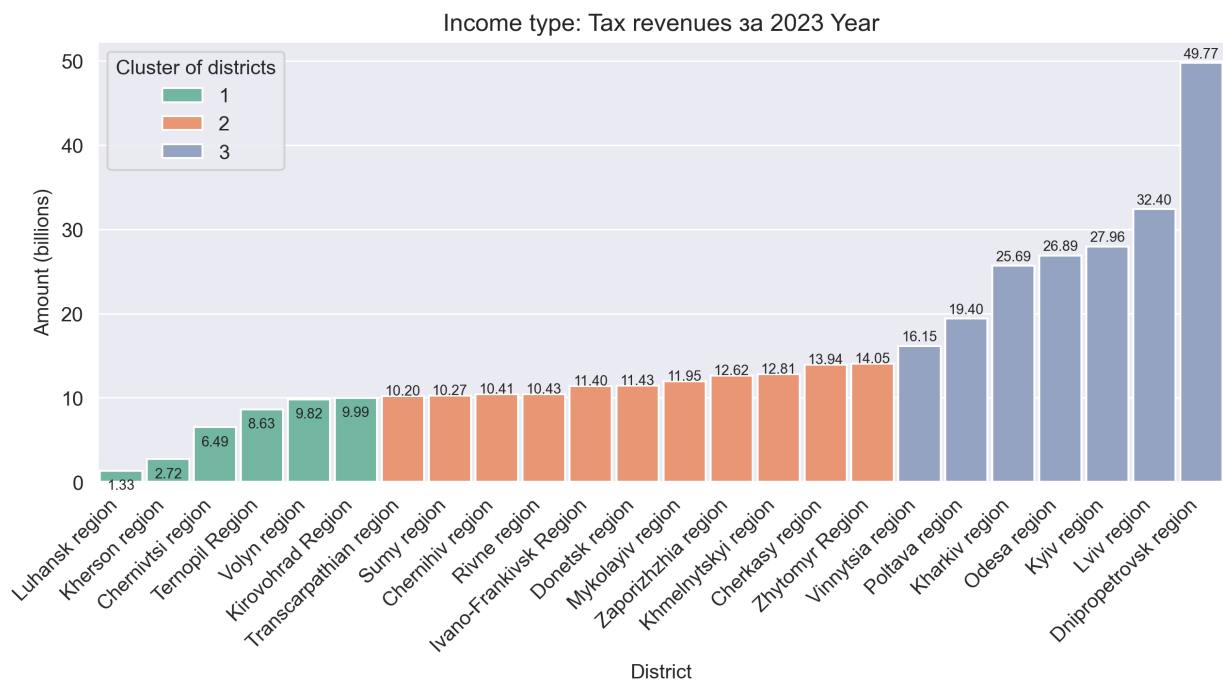
**Figure 5:** Clustering of regions by tax revenues of local budgets of Ukraine in 2020, billion UAH.



**Figure 6:** Clustering of regions by tax revenues of local budgets of Ukraine in 2021, billion UAH.

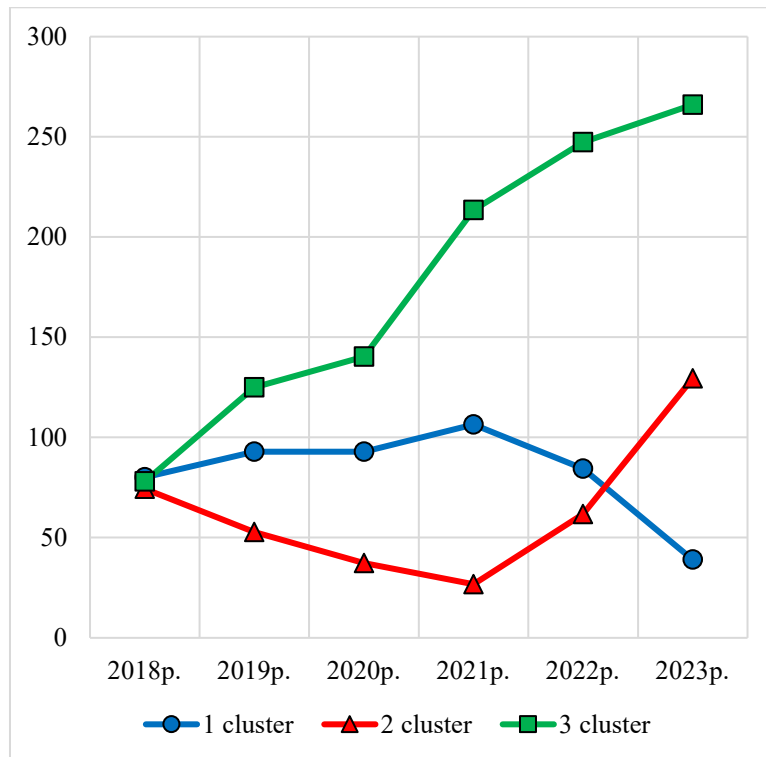


**Figure 7:** Clustering of regions by tax revenues of local budgets of Ukraine in 2022, UAH billion.



**Figure 8:** Clustering of regions by tax revenues of local budgets of Ukraine in 2023, billion UAH.

On the basis of the conducted analysis, fluctuations of the indicator of the number of regions within the cluster groups were determined. In particular, in 2018–2020, the largest specific weight in terms of the number of regions was occupied by 1 cluster (16 regions of Ukraine), in 2021 – 1 cluster, but 15 regions, in 2022 – 1 cluster with 9 regions, and in 2023 – 2 clusters (11 regions). Regarding the specific weight of the collected taxes and fees in the financial equivalent, trends have been determined that demonstrate the ambiguity of the group's influence on the overall indicator of tax revenues of a certain local budget (Fig. 9).



**Figure 9:** Cluster visualization of the dynamics of tax revenues in 2018-2023, UAH billion.

This indicates that special attention should be paid to the regions with medium tax potential (cluster 2) in making management decisions on taxation issues, instead, the policy of tax incentives should be implemented in the regions belonging to the 3rd cluster. The group of regions of cluster 1 was significantly affected by the introduction of the legal regime of martial law in Ukraine in 2022, in particular, territorial communities that are under temporary occupation or located in the front-line zone need alternative sources of financial support other than tax methods, namely: transfers, grants, loans, etc. (including international level).

#### 4. Conclusion

It is shown that the presence of sufficient tax revenues in local budgets is evidence that the territorial community is able to provide quality and various services to its residents as well as initiate social and infrastructure projects and create appropriate conditions for developing the entrepreneurship and investment attraction. As the result, the local community development programs are implemented, and the living conditions are improved, and the migration processes are stimulated at war and post-war conditions in Ukraine. Based on the use of machine learning technologies, the dynamics of tax revenues in the context of their influence on ensuring the development of the regions of Ukraine is determined. As a result of the clustering of the regions of Ukraine in terms of tax revenues and using the functionality of Matplotlib, groups of regions with moderate dynamics and a significant impact of the risks of martial law, decreasing dynamics until the beginning of countering military aggression and stabilization and growth in 2022-2023 were established, with steadily growing dynamics in the analyzed period, regardless of countermeasures against modern risks. Such an approach will serve as a basis for the formation of ways of increasing the tax potential of the relevant local budgets for the performance of functions by local self-government bodies, which will contribute to the provision of quality services to residents of territorial communities in Ukraine.

Increasing the role of local taxes and fees and increasing their share in own revenues of local budgets is one of the priority tasks for local self-government bodies. This involves diversifying fiscal competencies between levels of public authority through the delegation to local self-government bodies of exclusive powers to account for, charge, declare, use preferences and control the payment of local taxes and fees to



the budgets of territorial communities. Moreover, it will intensify the actions of structural units for the local self-government to fill state registers with up-to-date information data on property owners for taxation purposes using digitalization. This, in turn, will contribute to raise the standard of population living and increase living standards.

In the future, we are going to investigate the use of machine learning technologies in the context of determining the forecast indicators of tax revenues to the state and local budgets. In addition, we will explore the probability density indicators of continuous or non-parametric variable data on taxes and fees in order to identify the impact on the economy of Ukraine.

## Declaration on Generative AI

The authors have not employed any Generative AI tools.

## References

- [1] A. Smith, *An inquiry into the nature and causes of the wealth of nations*, London: Printed for W. Strahan; and T. Cadell, in the Strand, 1776. URL: [https://archive.org/details/inquiryintonatur01smit\\_0/page/n3/mode/2up](https://archive.org/details/inquiryintonatur01smit_0/page/n3/mode/2up)
- [2] A. E. Apeti, E. D. Edoh, Tax revenue and mobile money in developing countries, *Journal of Development Economics*, Elsevier 161 (2023) 10301.
- [3] T. T. Ho, X. H. Tran, Q. K. Nguyen. Tax revenue-economic growth relationship and the role of trade openness in developing countries. *Cogent Business & Management* 10 (2), 2023, 2213959–221. DOI: 10.1080/23311975.2023.2213959
- [4] V. Spyraakis, S. Kotsios, Public debt dynamics: the interaction with national income and fiscal policy, *Economic Structures* 10 (2021).
- [5] J. Jia, S. Ding, Y. Liu, Decentralization, incentives, and local tax enforcement, *Journal of Urban Economics* 115 (2020) 103225. Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0094119019301020>
- [6] S. Capasso, L. Cicatiello, E. Simone, G.L. Gaeta, P.R. Mourão. Fiscal transparency and tax ethics: does better information lead to greater compliance? *Journal of Policy Modeling*, 2021, 43.5: 1031-1050. DOI: 10.1016/j.jpolmod.2020.06.003
- [7] D. Carroll, L. Doherty V. André, E. R. Optimal fiscal reform with many taxes, FRB of Cleveland Working Paper No. 23-07R, (2024). <http://dx.doi.org/10.2139/ssrn.4352673>
- [8] B. Akitoby, A. Baum, C. Hackney, O. Harrison, K. Primus, V. Salins, Tax revenue mobilization episodes in developing countries, *Policy Design and Practice* 3 (2019), 1–29.
- [9] A. Krysovaty, O. Desyatnyuk, F. Tkachyk, Theoretical logics of fiscal decentralization in the conditions of permanent transformation of interbudgetary relations, *Financial and Credit Activity Problems of Theory and Practice* 2 (2022) 63–70.
- [10] F. J. Delgado, M. J. Presno, F. A. Blanco, Local taxation in the EU: A convergence study, *Journal of Regional Research – Investigaciones Regionales* 45 (2019) 263-271.
- [11] H. Ines, J. Stuhler, The Dynamic Response of Municipal Budgets to Revenue Shocks, *American Economic Journal: Applied Economics* 16 (2024) 484–527.
- [12] L. Gasparyniene, T. Klietk, R. Sivickiene, R. Remeikiene, M. Endrijaitis, Impact of Foreign Direct Investment on Tax Revenue: The Case of the European Union, *Journal of Competitiveness* 14 (2022) 43-60.
- [13] M. Z. Abedin, G. Chi, M. M. Uddin, M. S. Satu, M. I. Khan and P. Hajek, Tax Default Prediction Using Feature Transformation-Based Machine Learning, in *IEEE Access*, vol. 9, pp. 19864-19881, 2021, doi: 10.1109/ACCESS.2020.3048018
- [14] W. Didimo, L. Grilli, G. Liotta, L. Menconi, F. Montecchiani and D. Pagliuca, Combining Network Visualization and Data Mining for Tax Risk Assessment, in *IEEE Access*, vol. 8, pp. 16073-16086, 2020, doi: 10.1109/ACCESS.2020.2967974.
- [15] B.F. Murorunkwere, J.F. Ihirwe, I. Kayijuka, J. Nzabanita, D. Haughton. Comparison of Tree-Based Machine Learning Algorithms to Predict Reporting Behavior of Electronic Billing Machines. *Information* 2023, 14, 140. doi:10.3390/info14030140

- [16] Y. Zheng, H. Zheng, X. Ye, Using Machine Learning in Environmental Tax Reform Assessment for Sustainable Development: A Case Study of Hubei Province, China. *Sustainability* 2016, 8, 1124. doi:10.3390/su8111124
- [17] State Budget Web Portal for Citizens: Income. URL: <https://openbudget.gov.ua/national-budget/incomes> (in Ukrainian).
- [18] K. Lipianina-Honcharenko, C. Wolff, A. Sachenko, O. Desyatnyuk, S. Sachenko, I. Kit, Intelligent information system for product promotion in internet market, *Applied Sciences* 13 (2023) 9585. doi:10.3390/app13179585
- [19] A. H. Sial, S. Y. S. Rashdi, A. H. Khan, Comparative analysis of data visualization libraries Matplotlib and Seaborn in Python, *International Journal of Advanced Trends in Computer Science and Engineering* 10 (2021) 277–281.
- [20] K. Mabelane, W. T. Mongwe, R. Mbuva, T. Marwala. An Analysis of Local Government Financial Statement Audit Outcomes in a Developing Economy Using Machine Learning. *Sustainability* 2023, 15, 12. <https://doi.org/10.3390/su15010012>
- [21] H. Lipyanina, V. Maksymovych, A. Sachenko, T. Lendyuk, A. Fomenko, I. Kit, Assessing the investment risk of virtual IT company based on machine learning, In: Babichev, S., Peleshko, D., Vynokurova, O. (eds) *Data Stream Mining & Processing, DSMP 2020. Communications in Computer and Information Science*, vol. 1158, 2020. Springer, Cham. [https://doi.org/10.1007/978-3-030-61656-4\\_11](https://doi.org/10.1007/978-3-030-61656-4_11)
- [22] C. Swenson, Using Machine Deep Learning AI to Improve Forecasting of Tax Payments for Corporations. *Forecasting* 2024, 6, 968–984. doi:10.3390/forecast6040048
- [23] O. Desyatnyuk, M. Naumenko, I. Lytovchenko, O. Beketov, Impact of digitalization on international financial security in conditions of sustainable development, *Problemy Ekorozwoju* 19 (2024) 104–114. doi:10.35784/preko.5325
- [24] F. Fayziev, The role of local budgets in tax policy. *Modern Science and Research*, 2(5) (2023) 1315–1319. Retrieved from <https://inlibrary.uz/index.php/science-research/article/view/20713>
- [25] H. Lipyanina, S. Sachenko, T. Lendyuk, A. Sachenko, Targeting model of HEI video marketing based on classification tree, in *Proceedings of the ICTERI 2020 ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, CEUR Workshop Proceedings*, vol. 2732, pp. 487–498.
- [26] A. R. Marakhimov, K. K. Khudaybergenov, Approach to the synthesis of neural network structure during classification, *International Journal of Computing* 19 (2020) 20–26.
- [27] L. Kozarezenko, I. Tochylina, Tax advantages of local budgets as an instrument of financial capacity of territorial communities // *Baltic Journal of Economic Studies*. 2018. №4. URL: <https://cyberleninka.ru/article/n/tax-advantages-of-local-budgets-as-an-instrument-of-financial-capacity-of-territorial-communities>
- [28] L. S. Kirina, N. I. Malis, O. V. Mandroshchenko, N. A. Nazarova, & O. O. Yushkova, Tax revenues and balanced budgets. *European Research Studies Journal*, 21(1) (2018) 675–685.
- [29] E. M. Cherrat, R. Alaoui, & H. Bouzahir. Score fusion of finger vein and face for human recognition based on convolutional neural network model. *International Journal of Computing*, 19(1) (2020) 11–19. doi: 10.47839/ijc.19.1.1688
- [30] T. Hovorushchenko, V. Bachuk, Y. Hnatchuk, I. Zasornova, H. El Bouhissi. Overview of the methods and tools for environmental components monitoring. *Computer Systems and Information Technologies*, (2024) 351. doi: 10.31891/csit-2024-3-7UDC004.9