

N. M. Zayed*¹,
orcid.org/0000-0001-7519-6552,
N. R. Nahid¹,
orcid.org/0009-0004-2197-4880,
N. A. Ani¹,
orcid.org/0000-0003-2831-424X,
O. Tkachenko²,
orcid.org/0000-0003-2923-7186,
E. Varaksina³,
orcid.org/0000-0003-1351-6578,
N. Shyriaieva⁴,
orcid.org/0000-0002-2233-3581

1 – Daffodil International University, Dhaka, Bangladesh
2 – Kyiv National Economics University named after Vadym Hetman, Kyiv, Ukraine
3 – Poltava State Agrarian University, Poltava, Ukraine
4 – Odesa State Academy of Civil Engineering and Architecture, Odesa, Ukraine
* Corresponding author e-mail: zayed.bba@daffodilvarsity.edu.bd

IMPACT OF URBANIZATION AND CO₂ EMISSION ON GDP: A CASE STUDY OF UKRAINE

Purpose. Justification of the impact of carbon dioxide emissions and urbanization on economic growth in Ukraine.

Methodology. General and specific research methods were used. Quantitative research methods were based on econometric modeling, in particular, the use of the Generalized Method of Moments (GMM), and, to account for the non-stationarity of time series, Cointegration. Regression analysis was also used with multiple regression methods, which increased the relevance of the calculations. The method of comparing the results of these methodological approaches increased the reliability of the results.

Findings. In the case of Ukraine, a high level of influence of urbanization in Ukraine on GDP growth has been established, while carbon dioxide emissions do not play a significant role in increasing or decreasing GDP. Usually, this difference is explained by the different policies of Ukraine and the use of nuclear energy. The study proves that in Ukraine, the country has been able to increase its economic growth through environmentally friendly policies and urban planning. The conclusions presented in the study are also supported by the Environmental Kuznets Curve (EKC).

Originality. This study is the first to highlight the relation between urbanization and carbon dioxide emissions and Ukraine's economic growth. The significant impact of urbanization and CO₂ emission on GDP also has been tested by CUSUM and CUSUMQ tests for the first time.

Practical value. The results indicate that sustainable urbanization, the use of renewable energy, and the implementation of planned policies are important for Ukraine, which is essential for the country to maintain a balance between environmental impact and economic development in the long term. The results will be useful for employees of ministries and agencies, as well as researchers working on these issues.

Keywords: *carbon dioxide emissions, urbanization, sustainable development, GDP, environmental risk, environmental policy*

Introduction. The relationship between carbon dioxide emissions, urbanization, and GDP has become an important topic of discussion in the current world. As a result of the development of industrialization and urbanization, most people are now not living in rural areas. Consequently, power generation, vehicles and industrial activities have been increased. And with the increase in demand for these, the amount of CO₂ emissions in the environment has increased significantly. Various studies have shown that although economic activities have increased due to urbanization, it has also had an adverse impact on the environment. The level of environmental pollution has also increased excessively. Many developed countries of the world have been able to control CO₂ emissions to a great extent by using environmentally friendly technologies. CO₂ emissions decreases to a great extent due to various technological developments and policy measures. In this context, it is very important to accurately analyze how effective or harmful the combined effects of CO₂ and urbanization are on the current global economy. The main goal or objective of this study is to find the association among these factors. CO₂ emis-

sions and urbanization are closely related to the economic situation of our current world. There are several clear rationales for choosing in this context. Ukraine is a domestic energy-dependent economy. The infrastructure has been greatly disrupted due to the war. And this is why the impact of CO₂ emissions and urbanization has affected this country. The results of this study show that in Ukraine, urbanization has played a helpful role in increasing GDP, but the impact of CO₂ emissions is relatively much less. This is one of the opportunities for an analysis in the study. Again, through statistical model analysis, it is seen that the policy and economic structures of Ukraine have impacts on its environment and economy. The results obtained from this study can play a helpful role in creating future environmentally friendly policies of this country. Therefore, it is very logical and relevant to include Ukraine in this study.

Literature review. Many studies have shown that urbanization can increase energy efficiency through higher population density, improved infrastructure, and transportation systems. This can significantly reduce carbon dioxide emissions. However, it is also often seen that urbanization due to higher population density leads to increased industrial activities and vehicle use [1, 2]. This increases carbon dioxide emissions. The rate of urban-

ization is seen in Ukraine. However, there is some reduction or slowdown in infrastructure development due to war and political uncertainties, which can affect environmental impacts in various ways [3, 4]. Most studies conducted for developing and middle-income countries have clearly proven that there is a positive relationship between carbon dioxide emissions and GDP growth. The existing economy of Ukraine is dependent on natural resources and various fossil fuels [5, 6]. This accelerates carbon dioxide emissions along with GDP growth. However, some studies show the EKC hypothesis of the environment [7, 8]. Where carbon dioxide emissions increase in the initial stage for economic development, but later, due to the implementation of advanced technology and environmentally friendly policies, emissions decrease again [9, 10]. Ukraine uses a lot of fossil fuels. However, there is a significant share of nuclear energy, which emits relatively little carbon dioxide in this country [8]. However, there is a need to increase special attention and attraction to renewable energy in this country. This is especially seen in post-war Ukraine as part of the reconstruction of the country [11]. The wars in Ukraine have had a huge negative impact on the energy infrastructure and industrial systems, including urbanization. This has directly and indirectly increased the trend of carbon dioxide emissions. If the policy decisions made during and after the war are not environmentally friendly, long-term carbon dioxide emissions and climate change may occur in the regions of this country [12]. Sustainable urbanization plans need to be adopted as soon as possible in this country so that there is a balance between environmental protection and economic growth in this country [13, 14]. The government should encourage people to use renewable energy and environmentally friendly technologies. The path to reducing carbon dioxide emissions with economic growth without policy coordination is quite complex and difficult [15, 16]. Various studies have shown that negative shocks or unexpected declines in urbanization have a positive impact on economic growth. On the contrary, positive shocks or unexpected increases have a negative impact on economic growth. It is clear that excessive or rapid urbanization can sometimes have a negative impact on the country's economy such as overpopulation pressure and infrastructure crisis [17]. Reduction in energy consumption or negative shocks plays a role in increasing economic efficiency. Germany is that even if energy is used in small quantities, it is still possible to increase productivity. Similarly, excessive energy consumption or positive shocks are creating adverse effects on the economy [18]. This is usually due to waste or ineffective management. The use of fossil fuels has made a significant contribution to economic growth. This highlights the role or necessity of fossil fuels in China's developing industrial-based economy. The study shows that the impact of carbon dioxide emissions on economic growth is not significant in the long term. That is, even if emissions increase, it does not directly have a significant negative impact on GDP [19]. This study mainly emphasizes the promotion of renewable energy use and improvement of energy efficiency so that carbon dioxide emissions are greatly reduced. And at the same time, economic growth is also maintained in a certain balance. One thing here indicates that China is trying to

move towards more environmentally friendly energy by reducing its dependence on fossil fuels over time [20]. Urbanization is considered one of the main reasons for the increase in carbon dioxide. The tendency of most people to move to cities for a better life is increasing. As a result, there is a huge pressure on vehicles, housing, and industries in cities, which increases carbon dioxide emissions. Various studies have shown that if GDP increases by 1 %, carbon dioxide emissions increase by 0.4 %. This means that the more economic activities increase, the more energy is used, and the more carbon dioxide emissions increase.

Trade openness increases carbon dioxide emissions. Because of more import and export activities, along with the demand for industrialization and transportation, carbon dioxide emissions are accelerated. This study mainly provides guidance or suggestions for green urbanization, the development of industrial structures, as well as increasing the use of renewable energy. This reduces various environmental threats and ensures the improvement of public health. In the case of Ukraine, urbanization and economic growth also have a wide range of adverse effects on the environment. If the results of the study are analyzed for Ukraine, it will be understood how environmentally friendly policies can be used appropriately in urbanization and trade management [8, 21]. Various studies have shown that increasing energy efficiency reduces per capita carbon dioxide emissions. For every \$100 of GDP per ton of oil, there is an increase in energy efficiency of 17 to 64 kg of carbon dioxide emissions. That is, the more efficiently energy can be used, the fewer carbon dioxide emissions will be, which will also reduce environmental pollution. If GDP increases by \$1,000, then carbon dioxide emissions increase by 260 kg per capita. Economic growth leads to a significant increase in the country's industry, environment, and energy consumption. This opens the way for more carbon dioxide emissions and environmental pollution. With the increase in life expectancy, there is a greater impact on the health and service sectors. This not only increases energy demand but also accelerates carbon dioxide growth. In addition, high population growth directly affects the transportation system, including urbanization, in the country, which results in a significant increase in carbon dioxide emissions.

If per capita energy consumption increases, carbon dioxide emissions also increase. And it is not just an increase, but a significant increase. If people are given emphasis on increasing energy efficiency, carbon dioxide emissions will be reduced to a large extent. For example, the use of advanced technology and the increasing use of renewable energy. Creating less energy-intensive industrial sectors so that there is no adverse impact on the environment. This ensures long-term sustainable growth.

As a result of this study, Ukraine is deeply involved in the current energy-dependent infrastructure and various policy-making processes. Based on this study, one thing can be noted that the lack of energy efficiency and the absence of sustainable industrial policies are among the main reasons for carbon dioxide emissions. The relationship between urbanization and carbon dioxide emissions in the world's eight most populous countries. The study found that if the ratio of total urbanization to small cities increases, carbon dioxide emissions in-

crease. But if their square root value increases, emissions decrease. That is, although carbon dioxide increases in the initial stage due to urbanization, it decreases again later through improved technology and policies. The percentage of big cities reduces carbon dioxide emissions, but if its square root value increases again, emissions increase. GDP growth, including energy intensity, industrial growth, and transport infrastructure, all these factors lead to an increase in carbon dioxide emissions. Sustainable urbanization strategies such as green city planning, public transport development and the use of renewable energy, etc. should be implemented as soon as possible so as not to face various environmental threats. The context of this study includes the urbanization patterns of Ukraine, industrialization, and energy dependence. The results of this study can be utilized to learn or understand the carbon dioxide emission trends of Ukraine by applying the EKC hypothesis [22, 23]. The study found that along with the increase in foreign direct investment, carbon dioxide emissions also increase significantly. This shows that most of the foreign investments in Ukraine so far were in the industrial and energy-dependent sectors. This has had a negative impact on the environmental aspects of the country. One of the reasons for the increase in carbon dioxide in Ukraine is economic growth. If the country's industrialization, infrastructure construction, energy consumption, etc. increase, then CO₂ emissions increase [14, 24].

Ukraine is an energy-dependent and industrial-dependent country. If urbanization in this country is not environmentally friendly, CO₂ emissions will increase to a greater extent. It is important to restructure the urbanization policies and execute environmentally friendly plans [25]. However, in developed countries, the opposite picture can be observed. If fossil fuels are more polluting in a country, then the environmental impact of that country becomes much weaker [26–28].

In the case of Ukraine, GDP is mainly influenced by urbanization (Fig. 1).

Purpose. The purpose of this research is to examine the impact of CO₂ emissions and urbanization on GDP in Ukraine. The study uses STIRPAT-based GMM, OLS, and Cointegration models.

Methods. All the data have been collected from the World Bank's World Development Indicators (WDI) [29]. The selected time period was determined to cover the economic and environmental changes in Ukraine after its independence. That is, from 1991 to the latest available data. Variable Selection: This paper uses three main variables. These are:

1. Dependent variable: GDP growth rate, %.

2. Independent variables:

- carbon dioxide emission, metric tons per capita;

- urbanization rate, % of total population living in urban areas.

Analysis Method: Econometric research methods are used to analyze the data of this study. The steps of this analysis are described below:

1. Descriptive statistics: Analysis of the mean, standard deviation, maximum, and minimum values of each variable.

2. Correlation analysis: Determining the relationship between the variables.

3. Regression analysis: Measuring the impact of carbon dioxide and urbanization on GDP growth by applying Ordinary Least Squares (OLS).

Determining results using various models for Ukraine.

The theoretical framework of this study shows that the independent variables directly affect the dependent variables (Fig. 2).

Results. The main objective of the study was to conduct an analysis of the carbon dioxide emission problem and the impact of urbanization on GDP in Ukraine. Here, the data has been analyzed in detail by using various statistical methods, including various tests of stationarity of carbon dioxide rates in Ukraine.

The graph of Ukraine's carbon dioxide emissions shows a downward trend. Emissions fell sharply in the 1990s due to the economic crisis and restructuring of the industrial sector. Emissions have remained somewhat stable since the 2000s. However, in recent years, the downward trend has increased. The lowest carbon dioxide emissions were observed in 2020, which amounted to 3.37 metric tons (Fig. 3).

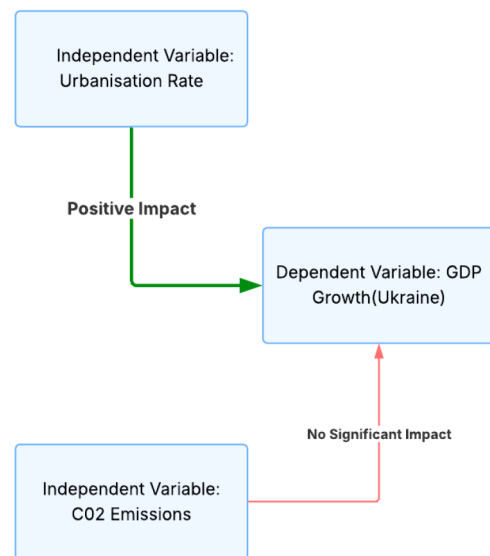


Fig. 1. Conceptual framework

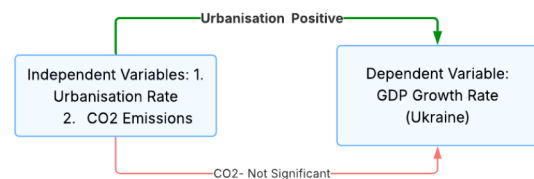


Fig. 2. Theoretical framework



Fig. 3. Graphical presentation of data: carbon emission

Table 1

Unit root tests: carbon emission

Test	Statistic	P-value	Critical values			Remarks
			1 %	5 %	10 %	
ADF	3.9587	0.0002	2.6347	1.951	1.6109	Stationary
PP	3.9752	0.0002	2.6347	1.951	1.6109	Stationary
KPSS	0.1704	—	0.7830	0.483	0.3470	Stationary

Here, the mean of emission is 7.65, and the variability is high ($SD = 3.01$). This suggests that there is a trend in the carbon dioxide data for this country and that the first difference is stationary. The high variability in Ukraine indicates the instability of the economic situation. However, the data period here is very limited, and more detailed models are needed for a more effective analysis (Table 1).

In the graph of Ukraine, the statistical summary of the urbanization analysis of Ukraine shows that the average urbanization rate in this country between 1990 and 2023 was -0.690 , with the highest rate being 1.265 and the lowest being -8.178 . The standard deviation is 1.805 , which indicates a high degree of instability (Fig. 4).

The GDP per capita trend of Ukraine shows that the average GDP between 1991 and 2023 is $32,413.99$ US dollars. The standard deviation is $45,944.31$ (Table 2).

Analyzing the graph of Ukraine, an economic crisis was seen between 1990 and 2000. There was a gradual recovery from this economic crisis between 2000 and 2014. Between 2014 and 2023, instability prevailed in Ukraine (Fig. 5).

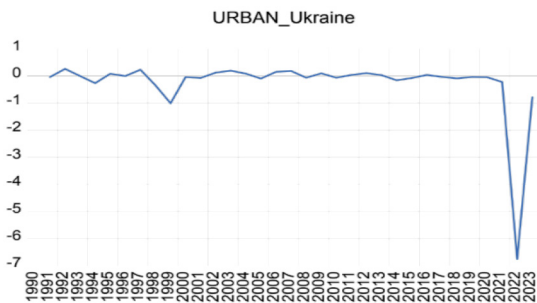


Fig. 4. Graphical presentation of data: urbanization

Table 2

Unit root tests: urbanization

Test	Statistic	P-value	Critical values			Remarks
			1 %	5 %	10 %	
ADF	4.8789	0	2.6347	1.9510	1.6109	Stationary
PP	4.8789	0	2.6347	1.9510	1.6109	Stationary
KPSS	0.2908	—	2.6347	0.4630	0.3470	Stationary

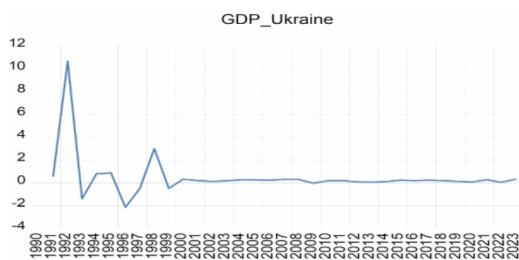


Fig. 5. Graphical presentation of data: GDP

The ADF and PP tests are non-stationary (p -value > 0.05), while KPSS test is stationary (LM-Statistic = $0.204 < \text{Critical Value}$). In the 2nd difference, the ADF and PP tests are stationary (p -value < 0.05). The cointegration analysis for Ukraine shows a strong long-term relationship (Table 3).

The results show that carbon dioxide decreases GDP (coefficient: $-5,843.4$), which indicates the failure of implementing environmentally friendly policies. Urbanization plays a supporting role in GDP growth (Coefficient: $-13,628.99$). From the above analysis, it can be concluded that in Ukraine, urban development plays a supporting role in increasing GDP. In the case of Ukraine, there is a strong positive correlation between urbanization and GDP. Here, just as GDP growth affects urbanization (p -value = 0.0000), urbanization also affects GDP (p -value = 0.0102) (Table 4).

One thing that can be understood from these results is that urbanization-based development policies in Ukraine play a supportive role in GDP growth. The impact of policies to reduce carbon dioxide emissions has been found to be neutral on the country's GDP, which leads to a new way of thinking about setting environmentally friendly policies. The GMM analysis shows the relationship between carbon dioxide, urbanization, and GDP for Ukraine. Urbanization positively affects GDP in the country ($p = 0.04$) (Table 5).

Here, the weak instrumental problem (J-statistic $p > 0.79$) in both cases has limited the reliability of the results to a large extent. From these results, it can be understood that urbanization-based development policies may be more effective for Ukraine. The study's limitations include weak instrumentation and negative R^2 , which highlight the need for future research to validate improved models (Table 6).

Here, the explanatory power of the model is much weaker ($R^2 = 0.160$). The CUSUMQ graph shows a large instability in the country between the period 2005 and 2010. This is likely due to the 2008 financial crisis. In the case of Ukraine, urbanization has a positive effect on GDP ($p = 0.053$) (Figs. 6 and 7).

In Ukraine, urbanization is much more important. However, in both cases, additional variables are needed to develop the model.

Conclusions. This study has mainly analyzed the impact of carbon dioxide emissions and urbanization on GDP in Ukraine. Statistical analysis has shown that in the case of Ukraine, it is seen that the country's GDP increases with urbanization growth, but the impact of carbon dioxide emissions is relatively low. In Ukraine, the development trend is different due to the implementation of nuclear energy. The results of the study partially but not completely support the EKC hypothesis. Initially, emissions increase with development, and later, due to technological and policy developments, these

Table 3

Unit root tests: GDP

Test	Statistic	P-value	Critical values			Remarks
			1 %	5 %	10 %	
ADF	15.74032	0	2.6368	1.9513	1.6107	Stationary
PP	15.74032	0	2.6368	1.9513	1.6107	Stationary
KPSS	0.367349	—	0.7500	0.4630	0.3470	Stationary

Table 4

Cointegration test results

Test Type	Hypothesized CE(s)	Eigenvalue	Test Statistic	Critical value (5 %)	p-value	Remarks
Trace Test	None*	0.64	18.37	29.71	0.00	1 equation
	At most 1	0.59	13.29	12.54	0.01	
	At most 2	0.01	0.23	3.84	0.63	
Max-Eigenvalue Test	None*	0.65	34.10	21.13	0.00	1 equation
	At most 1	0.29	15.85	14.35	0.01	
	At most 2	0.01	0.23	3.84	0.63	

Table 5

Granger causality test

H_0	Observations	F-Stat.	Probability	Results ($\alpha = 0.05$)
CO ₂ does not cause GDP	34	0.96	0.809	Fail to Reject (No Causality)
GDP does not cause CO ₂	34	2.5017	0.124	Fail to Reject (No Causality)
Urbanization does not cause GDP	34	7.5166	0.010	Reject (Causality Exists)
GDP does not cause Urbanization	34	83.1104	0.0000	Reject (Causality Exists)
Urbanization does not Granger Cause CO ₂	34	0.9025	0.35	Fail to Reject (No Causality)
CO ₂ does not Granger Cause Urbanization	34	0.0000	0.3933	Fail to Reject (No Causality)

Table 6

GMM and OLS regression results

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Significance
C (Constant)	1,786.31	3,737.63	0.4779	0.6362	Not Significant
CO ₂	11,931.68	17,658.26	0.6757	0.5044	Not Significant
Urbanization	4,522.81	2,110.98	2.1425	0.0404	Significant

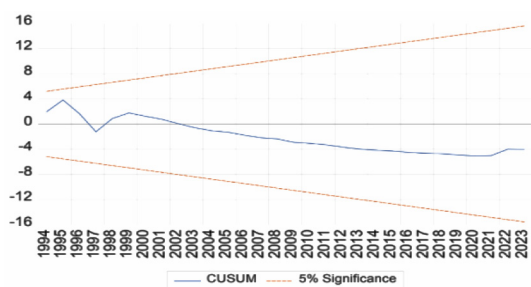


Fig. 6. CUSUM test

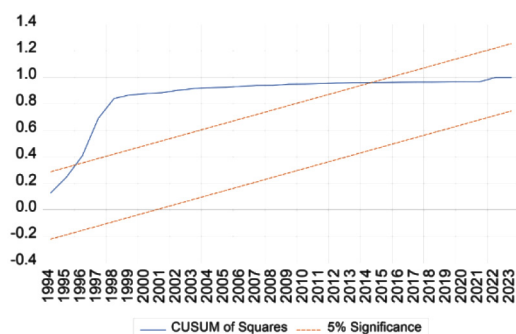


Fig. 7. CUSUMQ test

emissions decrease significantly. This study shows that not only development but also planned and sustainable urbanization and proper use of environmentally friendly energy are very important for the future. This study conveys an important message to policymakers, which is that, along with economic growth, it is equally important to properly maintain the environmental balance.

This study presents the need for sustainable urbanization and environmental economic policies in energy-dependent countries like Ukraine. The results of this study indicate that in the case of Ukraine, the planned urbanization system is increasing the economy to a large extent. Through this study, it can be seen how any country's industrial policy, energy use, and urban planning affect both the country's GDP and the environment. Based on the results of the study, it can be confirmed that different strategies can be adopted for the country. For example, Ukraine emphasizes the use of technology. In addition, this research will help shape development models for the future, promote economic development, and protect the environment.

This study has some limitations that are very important to consider in any future study. First, the data set used here is limited to a relatively short period (1991–2023). As a result, the study may be somewhat limited in its long-term observation. Second, the models used in this study, such as GMM and OLS, have shown weak instruments and low explanatory power in some cases. Due to the decline in export of goods, GDP has been affected in the current military situation (post-2022). People have been moved out from one place to another place because of the destruction of infrastructure. It also affected energy supply and CO₂ which changed the pattern of regular economy. That is how it might have affected the data and model of the research. As a consequence, the results of the study are somewhat limited in their reliability. Third, the situation in the country during the war, political instability, and international sanctions have affected the economic trends of the data, especially in Ukraine. This is considered an ef-

fect outside the scope of this study. However, if more advanced and powerful models are used in future studies, the data can be analyzed on a larger scale. It will make an important contribution to future studies by including local environmental and economic variability for the implementation of various improved policies.

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Вплив урбанізації та викидів CO₂ на ВВП: кейс України

Н. М. Заєд*¹, Н. Р. Нахід¹, Н. А. Ані¹,

О. В. Ткаченко², О. В. Вараксіна³, Н. Ю. Ширяєва⁴

1 – Міжнародний університет Дафоділ, м. Дакка, Бангладеш

2 – Київський національний економічний університет імені Вадима Гетьмана, м. Київ, Україна

3 – Полтавський державний аграрний університет, м. Полтава, Україна

4 – Одеська державна академія будівництва та архітектури, м. Одеса, Україна

* Автор-кореспондент e-mail: zayed.bba@daffodilvarsity.edu.bd

Мета. Обґрунтування впливу кількості викидів вуглекислого газу й процесу урбанізації на економічне зростання в Україні.

Методика. Використані загальні та спеціальні методи дослідження. Кількісні методи дослідження

спірались на економетричне моделювання, зокрема, використання загального методу моментів GMM, і для врахування нестационарності часових рядів – методу коінтеграції. Також використаний регресійний аналіз із застосуванням методів множинної регресії, що збільшувало релевантність розрахунків. Метод порівняння результатів названих методологічних підходів збільшив достовірність результатів.

Результати. Встановлено високий рівень впливу урбанізації в Україні на зростання ВВП. Доведено, що обсяги викидів вуглекислого газу не відіграють значної ролі у збільшенні чи зменшенні ВВП. Зазвичай цю різницю пояснюють різною політикою України й використанням ядерної енергії. Дослідження доводить, що Україна змогла збільшити економічне зростання завдяки екологічно безпечній політиці й міському плануванню. Приведені висновки у дослідженні також підтверджуються Екологічною кривою Кузнеця.

Наукова новизна. Дане дослідження вперше висвітлює зв'язок урбанізації та викидів вуглекислого газу із економічним зростанням України. Вплив урбанізації й викидів вуглекислого газу на ВВП був вперше перевірений з використанням тестів CUSUM і CUSUMQ.

Практична значимість. Результати показують, що стала урбанізація, використання відновлюваної енергії та впровадження планової економіки є важливими для України, та необхідним для підтримки балансу між навантаженням на довкілля й економічним розвитком у довгостроковій перспективі. Отримані результати стануть корисними для працівників міністерств і відомств, науковців, що займаються дослідженнями даних питань.

Ключові слова: викиди вуглекислого газу, урбанізація, сталий розвиток, ВВП, екологічний ризик, екологічна політика

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