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Economic Growth and Environmental Degradation: Data Intelligence for Sustainable Environment

Larysa Zomchak

Department of Economic Cybernetics, Ivan Franko National University of Lviv, Lviv, Ukraine. E-Mail: lzomchak@gmail.com

Maryna Nehrey*

*Corresponding Author, Department of Economic Cybernetics, National University of Life and Environmental Science of Ukraine, Kyiv, Ukraine. E-Mail: marina.nehrey@gmail.com

Marianna Oliskevych

Department of Mathematical Economics and Econometrics, Ivan Franko National University of Lviv, Lviv, Ukraine. E-Mail: olisk@ukr.net

Iryna Voronenko

Department of Information Systems and Technologies, National University of Life and Environmental Science of Ukraine, Kyiv, Ukraine. E-Mail: irynav@nubip.edu.ua

Nataliy Rogoza

Department of Economic Cybernetics, National University of Life and Environmental Science of Ukraine, Kyiv, Ukraine. E-Mail: nrogoza@nubip.edu.ua

Abstract

The article examines the nature of the relationship between environmental pollution and economic growth in Ukraine. An Data intelligence analysis of the dependence of pollutant emissions on GDP per capita and other factors of Ukraine's economy for the period from 1996 to 2018. The results of the econometric analysis confirm the theory of the Environmental Kuznets Curve. To prevent environmental and economic catastrophes, it is necessary to increase the gross regional product per capita, and this should be done by diversifying the economy, investing in clean production, and modernized equipment.

Keywords: Data intelligence, Economic Growth, Environmental Kuznets Curve, Environment, Econometric Analysis, Sustainability.

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Introduction

The problem of the relationship between economic growth and the state of the environment has a long history. One of the important issues of the ecological economy at the present stage is to find out how to treat the growth of the country's welfare. On the one hand, the increase in income stimulates consumption and production, the growth of which leads to an increase in waste generation and the use of natural resources and, accordingly, increases the anthropogenic impact. On the other hand, we can assume that with the growth of welfare, the demand for quality of life, including the quality of the environment. Sustainable development can be achieved only when economic growth is accompanied by a reduction in anthropogenic pressure on the environment and the rational use of available natural resources.

Until the 1980s, the impact on the environment was thought to increase with increasing economic activity. But since the introduction of the concept of sustainable development, which has been argued that economic development is not necessarily harmful to the environment and that poverty reduction is important for protecting the environment.

The Environmental Kuznets Curve (EKC) is a hypothetical relationship between various indicators of environmental degradation and per capita income. In the early stages of economic growth, degradation and pollution increase, but outside a certain level of per capita income, which will change for different indicators, the trend changes, so that at high-income levels, economic growth leads to an improvement in the environment. This means that the environmental impact indicator is the inverse U-shaped function of income per capita (Stern, 2004).

Summarizing the theoretical approaches, it can be argued that under certain theoretical assumptions it is possible to build a model that would describe the inverse U-shaped relationship between income and pollution. Although it should be noted that most of the considered approaches do not take into account the assimilation capabilities of natural systems, and it is difficult to predict the improvement of the environment without taking into account the possibilities of reproduction.

Literature Review

The problem of assessing the impact of environmental factors on economic development is complex, multifaceted, and long-term. A large number of studies on this issue are devoted to solving this problem.

In particular, the link between energy consumption and economic growth has been assessed in studies (Babenko et al., 2019), (Belaid & Zrelli, 2017), (Bielinskyi et al., 2021),(Kaganovska et al., 2022), (Koziuk, et al., 2020), (Pasko, et al., 2021, 2022). (Zaman & Abd-el Moemen, 2017), (Zherlitsyn et al., 2021), (Zomchak et al., 2022). The problem of using financial instruments in sustainable development management has been studied in (Bashtannyk et al., 2020), (Davydenko et al., 2019), (Dibrova et al., 2020), (Nasir et al., 2021), (Merkulova & et. al., 2018), (Merkulova & Kononova, 2016), (Nasir et al., 2021), (Samusevych et al., 2021).

The relationship between environmental factors and economic growth at the regional level has been studied in (Babenko et al., 2020), (Hryhoruk et al., 2020), (Klebanova et al., 2020), (Petrunenko et al., 2021).

The complexity of the studied problem has led to the use of a large number of scientific approaches and research methods, in particular in (Guryanova et al., 2020), (Matviychuk et al., 2019), (Mishchuk et al., 2020), (Skrypnyk et al., 2021).

The environmental Kuznets curve has been studied in (Churchill et al., 2018), (Dasgupta et al., 2002), (Destek & Sarkodie, 2019), (Destek et al., 2018), (Dogan & Inglesi-Lotz, 2019), (Friedl & Getzner, 2003), (Stern, 2004).

Methodology

Most of the researches considered simple data analysis curves, usually using second- and third-degree polynomials relative to GDP, often with the inclusion of additional factors:

$$P = \alpha_0 + \alpha_1 Y + \alpha_2 Y^2 + \varepsilon \quad (1)$$
$$P = \alpha_0 + \alpha_1 Y + \alpha_2 Y^2 + \alpha_3 Y^3 + \varepsilon \quad (2)$$

where P is the dependent change that describes the degradation of the environment; Y - income (GDP, GRP) per capita; ε is a random deviation; α0, α1, α2, α3– constants

Depending on the significance and signs of the coefficients αk, the relationship between economic growth and environmental quality can be determined as follows:

1) If α1= α2 = α3 = 0, then there is no relationship between P and Y;

2) If $\alpha1 > 0$, and $\alpha2 = \alpha3 = 0$, then there is a linearly increasing relationship;

3) If $\alpha1 < 0$, and $\alpha2 = \alpha3 = 0$, then there is a linearly decreasing relationship;

4) If $\alpha1 > 0$, and $\alpha2 < 0$ and $\alpha3 = 0$, then there is an inverse U-shaped relationship;

5) If $\alpha1 < 0$, and $\alpha2 > 0$ and $\alpha3 = 0$, then there is a U-shaped relationship;

6) If $\alpha1 > 0$, and $\alpha2 < 0$ and $\alpha3 > 0$, then there is an N-shaped relationship;

7) If $\alpha1 < 0$, and $\alpha2 > 0$ and $\alpha3 < 0$, then there is an inverse N-shaped relationship;

To confirm the hypothesis of the existence of EKC, the signs and significance of the coefficients must correspond to condition number four. In cases 6 and 7, in certain areas of economic growth, there is also a change in the quality of the environment by the theory of EKC (Stern, 2004).

There are tests to check the properties of stationarity in time series. The autocorrelation function and the correlogram can be used to check. The Dickie-Fuller test is common for EKC. The null hypothesis of the DF test indicates that there is a single root in the autoregression model, which means that some data are not stationary.

There are three versions of the test:

1. Without constant and trend:

$$\Delta y_t = b y_{t-1} + \varepsilon_t, \quad (3)$$

where $b = a - 1$,

$$\Delta y_t = y_t - y_{t-1}, \quad (4)$$

y_t– time series, ε – error.

With a constant, but without a trend:

$$\Delta y_t = b_0 + b_1 y_{t-1} + \varepsilon_t. \quad (5)$$

With constant and linear trend:

$$\Delta y_t = b_0 + b_1 y_{t-1} + b_2 t + \varepsilon_t. \quad (6)$$

An important step in building an adequate regression model is cointegration. This is the establishment of a long-term relationship, two or more rows of data will be combined. The cointegration equation looks like this:

$$y_{1t} = \sum_{i=2}^{k} a_i y_{it} + \varepsilon_t. \quad (7)$$

The error correction model is closely related to the concept of cointegration. That is a time series model in which short-term dynamics are adjusted depending on the deviation from the long-term relationship between variables. The error correction model is as follows (Stern, 2004):

$$\Delta y_t = \sum_{i=1}^{p} a_i \Delta y_{t-1} + \sum_{i=0}^{q} \beta_i \Delta x_{t-1} - \gamma(y_{t-1} - a_L - \beta_L x_{t-1}) + \varepsilon_t. \quad (8)$$

The hypothesis of the existence of EKC has not always been confirmed. For some types of pollution (wastewater, CO, SO2) studies have more often confirmed the hypothesis of the existence of EKC, for others (CO2) there is no unambiguous answer, in some cases the dependence is determined by cubic function or logarithmic (Fried and Getzner, 2003).

There is also a theory that economic activity inevitably involves the use of resources, and according to the laws of thermodynamics, the use of resources involves the production of waste. Regression, which allows the levels of indicators to become zero or negative, is inappropriate, except in cases of deforestation, where afforestation may occur. The nonzero constraint can be applied using a logarithmically dependent variable. Then the EKC regression model is:

$$lnE_{it} = \alpha_i + \gamma_t + \beta_1 lny_{it} + \beta_1 (lny_{it})^2 + \varepsilon_{it}, \quad (9)$$

where E is the quality of the environment or emissions per capita, Y is the gross domestic product per capita, ε is the random deviation. The first two terms on the right-hand side of the equation are interception parameters that vary depending on the countries or regions I and years t and are called country effects and time effects, respectively. The assumption is that, although the level of emissions per capita may vary from country to country at any given level of income, the elasticity of emissions is the same in all countries. Temporal interceptions are designed to account for time-varying variables and stochastic shocks common to all countries.

An important environmental task for most countries is to minimize the level of environmental degradation at the inflection point, from which the improvement of the environmental situation begins. Otherwise, the Earth's biosphere, due to environmental constraints, simply will not withstand such a large-scale transition from "poverty to wealth" with the formed man-made type of development.

Results

The impact on the environment, its degradation is closely related to the achieved level of the economic well-being of the country. Using the Kuznets curve, it is possible to prove that economic development does not always lead to environmental degradation, and in some cases even vice versa - the development of production at certain stages increases the number of ecologically certified industries and, consequently, reduces the negative impact on ecosystems.

The empirical basis for constructing models of the Kuznets ecological curve for Ukraine is the data of the State Statistics Service of Ukraine. Data from 1996 to 2018 are used to determine the nature of the relationship between environmental pollution and economic growth. The choice of the study period is due to two reasons. The first is the availability of data. Yes, some of the indicators used have only been available since 1996. Secondly, the beginning of the 90s in Ukraine is characterized by a decline in production and growth has been observed since 1996 of the XX century. The theory underlying the EKC is based on the assumption of economic growth and does not describe the processes occurring during a long economic downturn.

The factor that determines the level of economic development of Ukraine is the gross domestic product (GDP) per capita in constant 2011 prices. To reflect environmental pollution, factors are used such as emissions of nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon dioxide (CO2), and ammonia (NH3) measured in kg per capita. Also for each polluter, such indicators as production of the electric power measured in billion kW will be used. The full list of factors involved in building the model is presented in Table 1.

Table 1. Factors used in in Data intelligence analysis

GDP	GDP per capita, UAH
GDP2	Square of GDP per capita, UAH
NO2	Nitrogen dioxide per capita, kg
SO2	Carbon dioxide per capita, kg
CO2	Sulfur dioxide per capita, kg
NH3	Ammonia per capita, kg
ENERGY	Electricity production, billion kW
CPI	Chemical and petrochemical industry, UAH million
POP	Average population, mln
LS	Number of farm animals, thousand heads

To study the construction of an adequate model, a sufficient number of different indicators were tested, such as mechanical engineering, mining, and processing industry, steel production, production and distribution of electricity, gas, and water, and others. However, these factors were excluded from the evaluation of the model because they were not statistically significant and also formed multicollinearity between the factors.

The inclusion in the model of factors such as electricity generation, average population, and others, can help explain the process of growth and emission reductions as GDP grows.

A series of standard quality assessment tests are performed for each model. Detection of autocorrelation in the work can help the Brish-Godfrey test. This test tests the null hypothesis of no autocorrelation. Modified Wald statistics are used to detect heteroskedasticity in the remnants of the regression model. A test for the normal distribution of errors is also used to assess the adequacy of the model.

Despite the excellent performance of the Fisher test and the coefficient of determination, as well as the significance of the coefficients, the model can not be completely trusted. Another problem in evaluating the model may be the presence of non-stationary data used and the need to test the data for cointegration. If the variables are not stationary and there is no cointegration between them, the evaluation of the models may give erroneous results. If cointegration is available, additional evaluation methods are needed.

The Dickey-Fuller test was used to test for stationarity. The results of the assessment of stationarity proved for each pollutant proved that the data are not stationary, ie the null hypothesis of the presence of a single root is accepted. Using the necessary tools, data cointegration was identified.

For four models, an inflection point was also found, ie the point of maximum GDP per capita, at the achievement of which, the growth trend of environmental degradation, as economic growth changes to the opposite.

Because each of the four pollutants involved in the study is characterized by its own structure of sources, the results of model evaluations for each dependent variable will be considered separately.

Data on GDP per capita, electricity generation, and the chemical and petrochemical industries were used to construct the ECC model for such an indicator as nitrogen dioxide. The model will be the next:

$$NO_2 = \alpha_0 + \alpha_1 GDP + \alpha_2 GDP^2 + \beta_1 ENERGY + \beta_2 CPI. \quad (10)$$

Table 2 presents the correlation between the environmental indicator NO2 and economic indicators.

Table 2. Correlation between NO_2 and economic factors

	NO_2	GDP	GDP^2	ENERGY	CPI
NO_2	1,0000				
GDP	-0,7314	1,0000			
GDP^2	-0,3891	0,9470	1,0000		
ENERGY	0,7746	-0,4281	-0,4748	1,0000	
CPI	0,6897	0,4423	0,34990	0,0755	1,0000

The results of table 2 showed that nitrogen dioxide and GDP per capita have a sufficiently high inverse correlation, which means confirmation of the EKC hypothesis. There is no multicollinearity between the factors. There is also a fairly close relationship between NO2 and electricity and chemical and petrochemical production.

In Table 3 presents the results of model evaluation. According to the test results in the model, there is no autocorrelation and heteroskedasticity. Errors are distributed according to the normal distribution.

Table 3. Estimation of the Kuznets model for nitrogen dioxide

	Coefficient	Standard error	t-statistics	P-value
const	-9,1423	2,3487	-3,8920	0,0011***
GDP	0,0000	0,0000	3,8780	0,0011***
GDP^2	0,0000	0,0000	-4,3220	0,0004***
ENERGY	0,1001	0,0134	7,4520	6,63e-07***
CPI	0,0000	0,0000	2,5490	0,0201**

The parameters of the model are statistically significant. The coefficients α1> 0 and α2 <0 indicate the quadratic dependence of NO2 emissions on GDP per capita, and this dependence corresponds to the concept of EKC. The coefficient of determination is high and is 0.9307. Fig. 1 shows the inflection point.

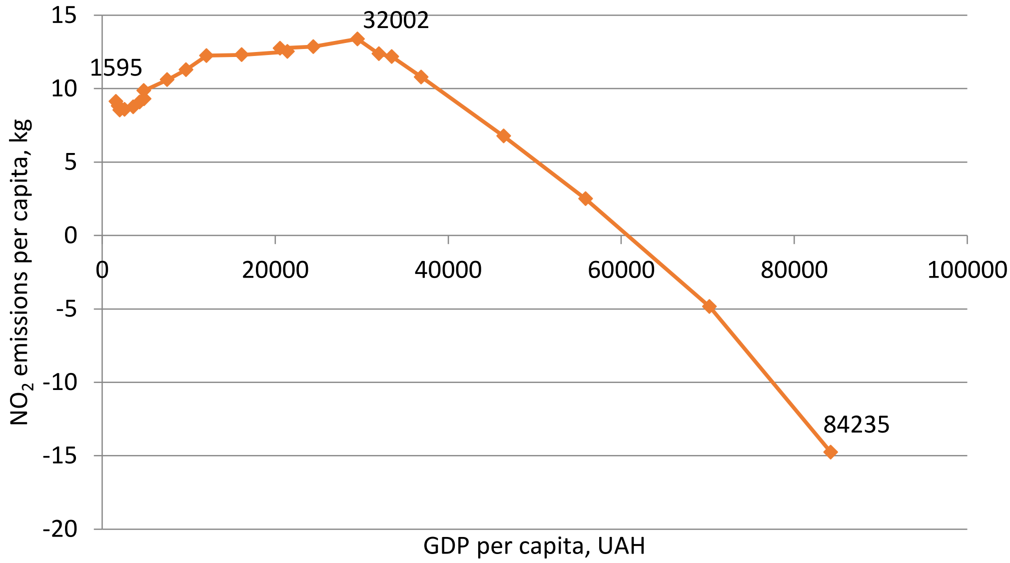

Figure 1. Changes in NO2 emissions depending on Ukraine's GDP

It can be concluded that the decline in NO2 emissions begins when the GDP per capita is 32002 UAH.

The ENERGY coefficient is significant and positive. The growth of the electricity generation sector is characterized by an increase in nitrogen dioxide emissions. The CPI sign is also positive, indicating a direct relationship between the pollutant and the chemical industry.

In order to identify the relationship between GDP per capita and sulfur dioxide emissions, the following model should be evaluated:

$$SO_2 = \alpha_0 + \alpha_1 GDP + \alpha_2 GDP^2 + \beta_1 ENERGY + \beta_2 POP. \quad (11)$$

Correlations between variables are shown in Table 4.

Table 4. Correlation between SO_2 and economic factors

	SO_2	GDP	GDP^2	ENERGY	POP
SO_2	1,0000				
GDP	-0,6013	1,0000			
GDP^2	-0,3457	0,9470	1,0000		
ENERGY	0,7935	-0,4281	-0,5748	1,0000	
POP	-0,6794	-0,8084	-0,7604	0,2654	1,0000

In the SO2 model, it can be observed that there is a relationship between population and GDP per capita. However, the presence of a correlation is usually not enough to conclude the existence of a causal relationship. Therefore, one cannot be sufficiently sure of the presence of multicollinearity in the model.

Table 5 presents model estimates for sulfur dioxide. In the estimated models there is no autocorrelation, heteroskedasticity, errors are distributed according to the normal distribution.

Table 5. Estimation of the Kuznets model for sulfur dioxide

	Coefficient	Standard error	t-statistics	P-value
const	-62,0761	26,3180	-2,3590	0,0298**
GDP	0,0005	0,0001	3,7310	0,0015***
GDP^2	-4,98e-09	1,22e-09	-4,0910	0,0007***
ENERGY	0,1972	0,0418	4,7170	0,0002***
CPI	0,9623	0,5358	1,7960	0,0893*

The level of statistical significance of the model parameters is high, except for the population, which is acceptable. The coefficients α1> 0 and α2 <0, so the model corresponds to the ECC. The coefficient of determination is equal to 0.82. The EKC graph for SO2 is shown in Fig. 2. The inflection point, as for nitrogen dioxide, falls in 2012, when GDP per capita was UAH 32,002.

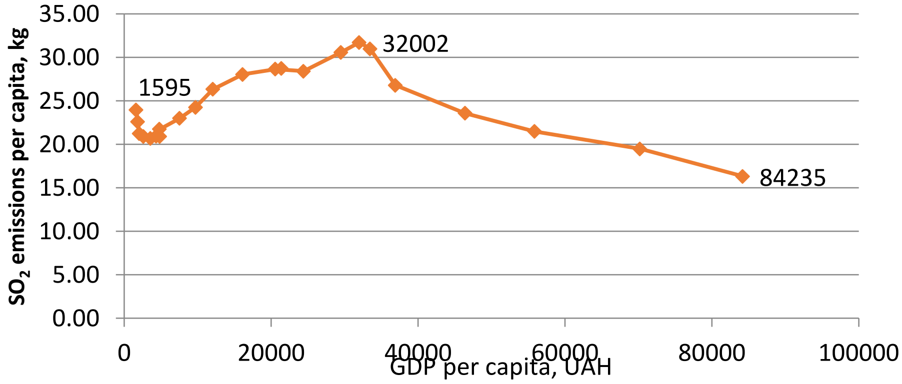

Figure 2. Changes in SO2 emissions depending on Ukraine's GDP

As expected, the increase in electricity production has a negative impact on sulfur dioxide emissions. Since this gas is released from the combustion of various fuels. The population is also directly dependent on SO2.

To assess the model of the relationship between CO2 and GDP, only one additional factor is used:

$$CO_2 = \alpha_0 + \alpha_1 GDP + \alpha_2 GDP^2 + \beta_1 ENERGY. \quad (12)$$

The correlation matrix is presented in Table 6.

Table 6. Correlation between SO2 and economic factors

	CO_2	GDP	GDP^2	ENERGY
CO_2	1,0000			
GDP	-0,6013	1,0000		
GDP^2	-0,3457	0,9470	1,0000	
ENERGY	0,7935	-0,4281	-0,5748	1,0000

The EKC hypothesis is confirmed, as there is a significant inverse relationship between CO2 and GDP per capita. There is no multicollinearity.

Table 7 presents the results of the evaluation of the model for carbon dioxide. Using the necessary tests, it was determined that autocorrelation and heteroskedasticity are absent for this model, and errors are distributed according to the normal distribution.

Table 7. Estimation of the Kuznets model for carbon dioxide

	Coefficient	Standard error	t-statistics	P-value
const	-0,5964	0,8806	-0,6773	0,0564*
GDP	2,44e-05	7,13e-06	-3,425	0,0028***
GDP^2	-2,59e-010	1,02e-010	2,540	0,0200**
ENERGY	0,0402	0,0049	8,113	1,36e-07***

Table 7 shows that the coefficients α1> 0 and α2 <0, ie there is an inverse U-shaped bond. Almost all parameters are quite statistically significant. The coefficient of determination is quite high, is 0.85. Appendix B shows a more detailed assessment of the model. Figure 3 shows the relationship between CO2 and GDP per capita. As in previous studies of the models, the inflection point falls in 2012.

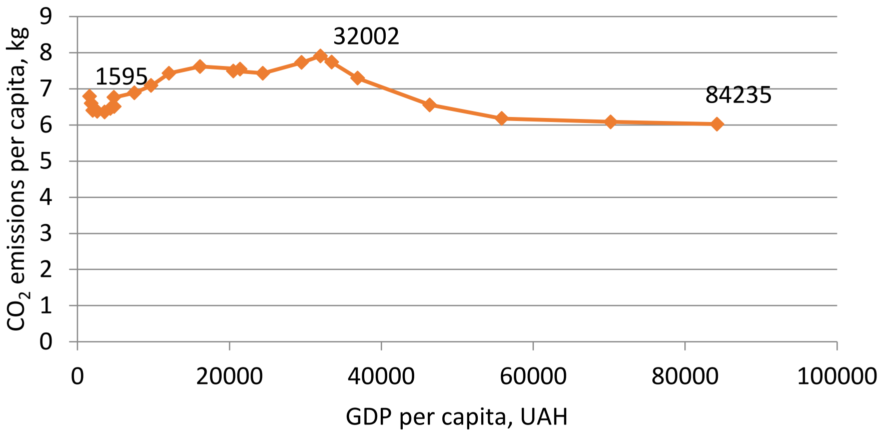

Figure 3. Changes in CO2 emissions depending on Ukraine's GDP

From the evaluation of the model, it can be observed that the increase in electricity production has an inverse relationship with CO2 emissions. Population, production, and forestry indicators were tested for this model, but with a high correlation with carbon dioxide emissions, these indicators were statistically insignificant.

Additional factors such as electricity generation and the number of farm animals were used to build a model of the relationship between ammonia emissions and GDP per capita. The model is the next:

$$NH_3 = \alpha_0 + \alpha_1 GDP + \alpha_2 GDP^2 + \beta_1 ENERGY + \beta_2 LS. \quad (13)$$

Table 8 shows the correlation between the environmental indicator NH3 and the indicators of the economy.

Table 8. Correlation between NH3 and economic factors

	NH_3	GDP	GDP^2	ENERGY	LS
NH_3	1,0000				
GDP	-0,5091	1,0000			
GDP^2	0,1457	0,9470	1,0000		
ENERGY	0,5169	-0,4281	-0,5748	1,0000	
LS	0,7846	-0,7280	-0,5328	-0,0032	1,0000

The model has a sufficient correlation between the pollutant and variables. There is no multicollinearity.

Table 9 presents the results of the model evaluation. According to the results of the Breusch–Godfrey and Wald tests, the model lacks autocorrelation and heteroskedasticity. Errors are distributed according to the normal distribution.

Table 9. Estimation of the Kuznets model for ammonia

	Coefficient	Standard error	t-statistics	P-value
const	-0,4371	0,1579	-2,768	0,0127**
GDP	6,32e-06	1,8e-06	3,503	0,0025***
GDP^2	-6,2e-011	2,01e-011	-3,083	0,0064***
ENERGY	0,0047	0,0008	5,866	1,48e-05***
LS	6,0e-06	2,02e-06	-2,976	0,0081***

All parameters of the model are statistically significant as shown in Table 9. The GDP and GDP2 ratios point to the hypothesis of an inverse U-shaped dependence of ammonia emissions on economic growth. The coefficient of determination is high and is 0.91. Fig. 4 shows the EKC for ammonia per capita. The inflection point is UAH 32,002 of GDP per capita.

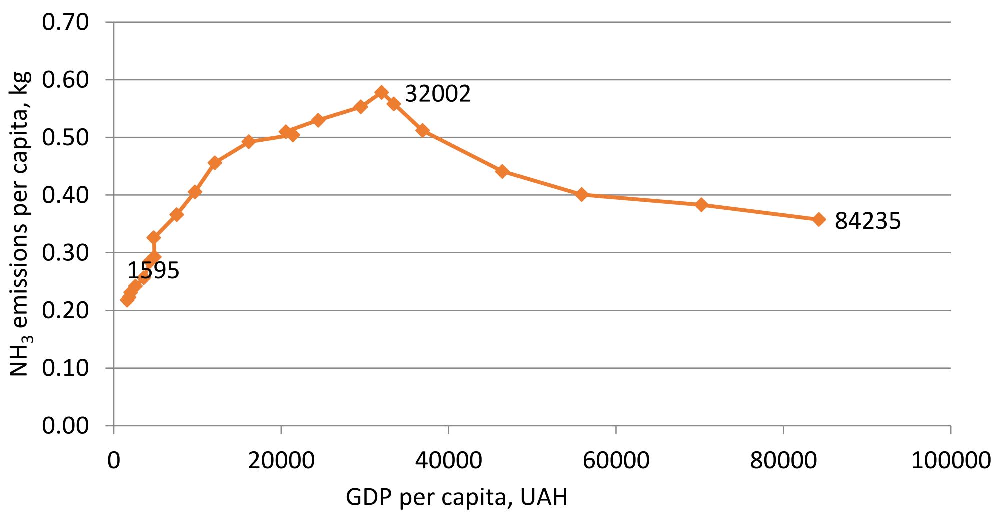

Figure 4. Changes in NH3 emissions depending on Ukraine's GDP

The values of the estimated coefficients are as follows: the growth of electricity production contributes to the increase of ammonia, this is because the combustion of fuels emits NO2 and SO2, which do not indirectly affect the formation of ammonia in the atmosphere. The number of farm animals is also directly related to the air pollutant.

Discussions

In each of the four models, the significant parameters are quite high, there is no autocorrelation and heteroskedasticity, there is cointegration, the coefficient of determination exceeds 0.80. Thus, the results of the necessary tests indicate that the obtained models can be considered adequate. Empirical analysis showed the presence of an inverse U-shaped dependence of pollutant emissions on GDP per capita and other economic factors in Ukraine for the period from 1996 to 2018. It can also be concluded that a steady decline in pollution begins in 2012 when GDP per capita was UAH 32,002. The study found that the greatest impact on the environment of Ukraine has the energy sector, respectively, the modernization of this industry will have a significant effect. Of course, the Kuznets curve hypothesis for pollutants requires further research and the inclusion of other economic factors in the model for a more detailed consideration of the relationship.

Conclusion

The results of the econometric analysis confirm the theory of the Environmental Kuznets Curve. Today, the development of the country's economy cannot be considered sustainable, which reduces emissions with the growth of gross regional product per capita. This is due to the raw material dependence of the economy, as well as the underdevelopment of social and economic institutions. To prevent environmental and economic catastrophes, it is necessary to increase the gross regional product per capita, and this should be done by diversifying the economy, investing in clean production, and modernized equipment.

Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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