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ECONOMETRIC ANALYSIS OF SUSTAINABLE NATIONAL ECONOMY DEVELOPMENT

Purpose. The study objective was to model conditions, mechanisms and opportunities to achieve sustainable development parameters for the national economy.

Methods. Analysis and synthesis, induction and deduction, analytical grouping and special (abstraction, modelling, etc.) methods of studying economic phenomena and processes have been used.

Results. Based on the analysis of the dynamics of GDP growth rates, sulfur dioxide, nitrogen dioxide, oxide and carbon dioxide emissions during 1991-2017, the cycle of their change lasting 3 - 5 years has been proved. It has been found out that the Environmental Kuznets Curve (EKC) in Ukraine is a specific one due to the "turning points". According to the results of comparing the cyclicality of per capita income growth rates, GDP indexes with the dynamics of dependence between the hazardous substances emissions and per capita income and GDP in actual prices, it is found that they do not always coincide. It gives grounds to make a conclusion about the presence of lag between the emissions volumes changes and values of per capita income and GDP in actual prices. The conclusions are grounded on the comparison of the dynamics of GDP growth rates, income per capita, pollutant emissions and the parameters of their mutual correlation. It has been proposed to carry out coordinated policy referring its economic, social and environmental components, taking into account the time lag to create the conditions for the EKC curve parameters in the economy of Ukraine.

Conclusions. . Based on the analysis of GDP growth rates dynamics, sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions, the periodicity (cyclicality) of their change has been proved. In Ukraine, EKC has a specific nature in the form of separate «turning points», without achievement of long-term parameters of the relationship between the hazardous substances emissions and GDP and per capita income values. Thus, the feasibility of developing the agreed policy concerning the economic (GDP value), social (population income level) and environmental components (conservation activity financing and decrease of hazardous substances emissions) taking into account the time lag, which will create the conditions for achieving not only temporary values, but also long-term parameters of EKC curve in the Ukrainian economy, was substantiated. The obtained results allow to forecast sustainable development parameters of Ukraine for the future.

KEY WORDS: sustainable development, economic growth, GDP, income per capita, national economy, emissions of air pollutants

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ЕКОНОМЕТРИЧНИЙ АНАЛІЗ СТАЛОГО РОЗВИТКУ НАЦІОНАЛЬНОГО ГОСПОДАРСТВА

Мета. Моделювання умов, механізмів та можливостей досягнення параметрів сталого розвитку національного господарства.

Методи. Загальнонаукові (аналіз та синтез, індукція та дедукція, аналітичне групування) та спеціальні (абстрагування, моделювання і т. ін.) методи вивчення економічних явищ і процесів.

Результати. На основі аналізу динаміки темпів зростання ВВП, викидів діоксида сірки, діоксида азоту, оксида та диоксида вуглецю впродовж 1991-2017 років доведена періодичність (циклічність) їх зміни тривалістю 3 – 5 років. Встановлено, що в Україні екологічна крива Кузнеця (ЕКК) має специфічний характер у вигляді окремих «поворотних точок». Висновки зроблено на підставі співставлення динаміки темпів зростання ВВП, доходів на душу населення й викидів забруднюючих речовин та параметрів взаємної кореляції між ними. За результатами порівняння циклічності темпів зростання доходів на душу населення, індексів ВВП з динамікою залежності між викидами шкідливих речовин та величин доходів на душу населення та ВВП у фактичних цінах, встановлено, що вони не завжди співпадають. Це дало підстави зробити висновок про наявність лагу між змінами обсягів викидів та величинами доходів на душу населення та ВВП у фактичних цінах. Запропоновано здійснювати формування узгодженої політики щодо економічної, соціальної та екологічної складових з урахуванням часового лагу задля створення умов для досягнення параметрів кривої ЕКК в економіці України.

Висновки. На основі аналізу динаміки темпів зростання ВВП, діоксиду сірки, діоксиду азоту, викидів оксидів вуглецю та діоксиду, доведена періодичність (циклічність) їх зміни. В Україні ЕКС має специфічний характер у вигляді окремих «поворотних точок», без досягнення довгострокових параметрів взаємозв'язку між викидами шкідливих речовин та ВВП та значеннями доходу на душу населення. Таким чином, доцільною є розробка узгодженої політики щодо економічної (величина ВВП), соціальної (рівень доходу населення) та екологічних складових (фінансування природоохоронної діяльності та зменшення викидів небезпечних речовин) з урахуванням часового лагу, що створить умови для обґрунтованого досягнення не лише тимчасових значень, а й довгострокових параметрів кривої ЕКС в українській економіці. Отримані результати дозволяють здійснювати прогнозування параметрів сталого розвитку України на перспективу.

КЛЮЧОВІ СЛОВА: сталий розвиток, економічне зростання, ВВП, доходи на одного працюючого, національне господарство, викиди забруднюючих речовин

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ЭКОНОМЕТРИЧЕСКИЙ АНАЛИЗ УСТОЙЧИВОГО РАЗВИТИЯ НАЦИОНАЛЬНОГО ХОЗЯЙСТВА

Цель. Моделирование условий, механизмов и возможностей достижения параметров устойчивого развития национального хозяйства.

Методы. Общенаучные (анализ и синтез, индукция и дедукция, аналитическое группировки) и специальные (абстрагирование, моделирование и т. д.) методы изучения экономических явлений и процессов.

Результаты. На основе анализа динамики темпов роста ВВП, выбросов диоксида серы, диоксида азота, оксида и диоксида углерода в течение 1991-2017 годов доказана периодичность (цикличность) их изменения продолжительностью 3 - 5 лет. Установлено, что в Украине экологическая кривая Кузнеца (ЭКК) имеет специфический характер в виде отдельных «поворотных точек». Выводы сделаны на основании сопоставления динамики темпов роста ВВП, доходов на душу населения и выбросов загрязняющих веществ и параметров взаимной корреляции между ними. По результатам сравнения цикличности темпов роста доходов на душу населения, индексов ВВП с динамикой зависимости между выбросами вредных веществ и величин доходов на душу населения и ВВП в фактических ценах, установлено, что они не всегда совпадают. Это дало основания сделать вывод о наличии лага между изменениями объемов выбросов и величинами доходов на душу населения и ВВП в фактических ценах. Предложено осуществлять формирование согласованной политики по экономической, социальной и экологической составляющих с учетом временного лага для создания условий для достижения параметров кривой ЭКК в экономике Украины.

Выводы. На основе анализа динамики темпов роста ВВП, диоксида серы, диоксида азота, выбросов оксидов углерода и диоксида, доказана периодичность (цикличность) их изменения. В Украине ЕКС имеет специфический характер в виде отдельных «поворотных точек», без достижения долгосрочных параметров взаимосвязи между выбросами вредных веществ и ВВП и значениями дохода на душу населения. Таким образом,, целесообразна разработка согласованной политики по экономической (величина ВВП), социальной (уровень дохода населения) и экологической составляющих (финансирование природоохранной деятельности и уменьшения выбросов опасных веществ) с учетом часового лага, что создаст условия для обоснованного достижения не только временных значений, но и долгосрочных параметров кривой ЕКС в украинской экономике. Полученные результаты позволяют осуществлять прогнозирование параметров устойчивого развития Украины на перспективу.

КЛЮЧЕВЫЕ СЛОВА: устойчивое развитие, экономический рост, ВВП, доходы на одного работающего, национальное хозяйство, выбросы загрязняющих веществ

Introduction

The global threats that the world faces and that are connected with the environmental problems substantiate the need to form the parameters, conditions and mechanisms of sustainable development. It is relevant first of all for developing countries, including for Ukraine. The aim of the paper is to forming the national economy sustainable development model taking into account new realities, peculiarities of economic systems, availability of resources, environmental state, production volumes, populations' standards of living and other factors of internal and external environment.

The problems of economic growth, factors that form it and ensure the national economy sustainable development attract more and more attention. The problems of sustainable development are traditionally studied with defining the economic, environmental and social determinants [1-5]. Concerning the relationship between the economic and environmental components, one of the models was proposed by Simon Kuznets, according to which there exists the relationship between the income (economic growth) and environmental pollution, which is of nonlinear nature – a form of reversed parabolic curve. This model remains relevant, gets new interpretations and can be used for characterising the problems of today, namely the problems of forming the national economy sustainable development model taking into account new realities, peculiarities of economic systems, availability of resources, environmental state, production volumes, populations' standards of living and other factors of internal and external environment.

Environmental Kuznets curve (EKC) dependence takes into account the influence of such main factors as: a) scale of production effect, i.e. its extension with the unchanged production factors, directions of influence on the environment and technological level; b) changes in the composition of pollutants emissions and other factors affecting the environment (output mix). The economic growth is accompanied by the change of emissions compositions, as different industries have different pollution intensiveness; c) change of production factors, in particular consumption of raw materials (input mix), which lead to replacing the less environmentally harmful factors with more environmentally harmful factors and vice versa; d) state of technology improvement, which predetermine the changes in production efficiency in the aspect of resource saving and decreasing the amount of waste per product (release) unit and pollutants emissions into the environment (emissions) per unit of the raw materials used.

These variables can feel the effect of such other factors as environmental regulation, education and awareness in the socio-economic development issues. A number of publications describe the theoretical models of how the state assistance and technologies can affect the environmental quality in different periods of time. Different hypotheses in order to simplify the description of the economy are presented in the studies. In the majority of them, there appears the possibility of creating the inverted U-shaped curve of the change of pollution intensiveness, but there is no agreement concerning its inevitability. The results of the studies depend on the hypotheses presented and the values of main parameters. Some researchers tell about the conditions of unchanged means of living, exogenous nature of technological changes and that it is not consumption but production that leads to pollution [7-8]. Other created the so-called cross-contamination models, according to which it is not production but consumption that causes contamination [9-10]. Stokey [11] assumed that the technical changes are of endogenous nature. Stern [12] notes that, based on some assumptions, it is easy to create a model, from which environmental Kuznets curve appears, but none of these models was proved empirically. If the monotonous dynamics of the pollutants emissions is proved by empirical studies, then the ability of EKC to create the inverted U-shaped curve of changes is not its property, but the separate case.

The evolutionary approach to assessing the factors that cause EKC was used by Cantore [13] who, unlike other researchers, used not the econometric instruments but the climate change complex assessment model RICE99 interpreted by Nordhaus and Boyer [14,15], which is one of the newest versions of regional dynamic general equilibrium model, developed by Nordhaus for studying the economic aspects of climate changes [14,15]. Such model was developed for each of eight macroregions, which the world is divided into (USA, other high-income countries, OECD European states, Russia and Eastern European countries, average-income states, below average-income states, China and low-income countries). According to it, it is assumed that every region chooses the most optimal investment trajectory and energy consumption expenditures, which maximise the per capita discounted consumption cost (GDP). He studied the factors that can neutralise the scale effect in the relationship between the income and environmental degradation: economic structure (production of goods and services), effectiveness of the resources usage (resource units per product unit), technological changes (replacement of scarce resources with the environmentally friendly technologies, which can decrease the environmental degradation).

Method

In the analysis, general-scientific methods (analysis and synthesis, induction and deduction) and special methods of phenomena and processes analysis (abstraction, econometric and econometric-mathematical modelling) have been used.

Results

The dynamics of GDP growth rates, sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions in Ukraine as a whole can be observed based on the data of State Statistic Service of Ukraine. It was done for 1991–2017 period, which showed some dependencies (Fig. 1).

The listed indicators change cyclically. So, at the GDP index curves, there are the minimums in 1994, 1998, 2002, 2005, 2009 and 2014, which correspond to the country's economic recessions. The GDP indexes maximums correspond to 2000, 2003, 2007 and 2010. The minimums at the per capita income growth rates dynamics curve are observed in 1998, 2002, 2006, 2009 and 2014. The corresponding maximums are observed in 2000, 2004, 2008, 2015. Thus, it can be seen that the duration of small cycles is from 3 to 5 years.

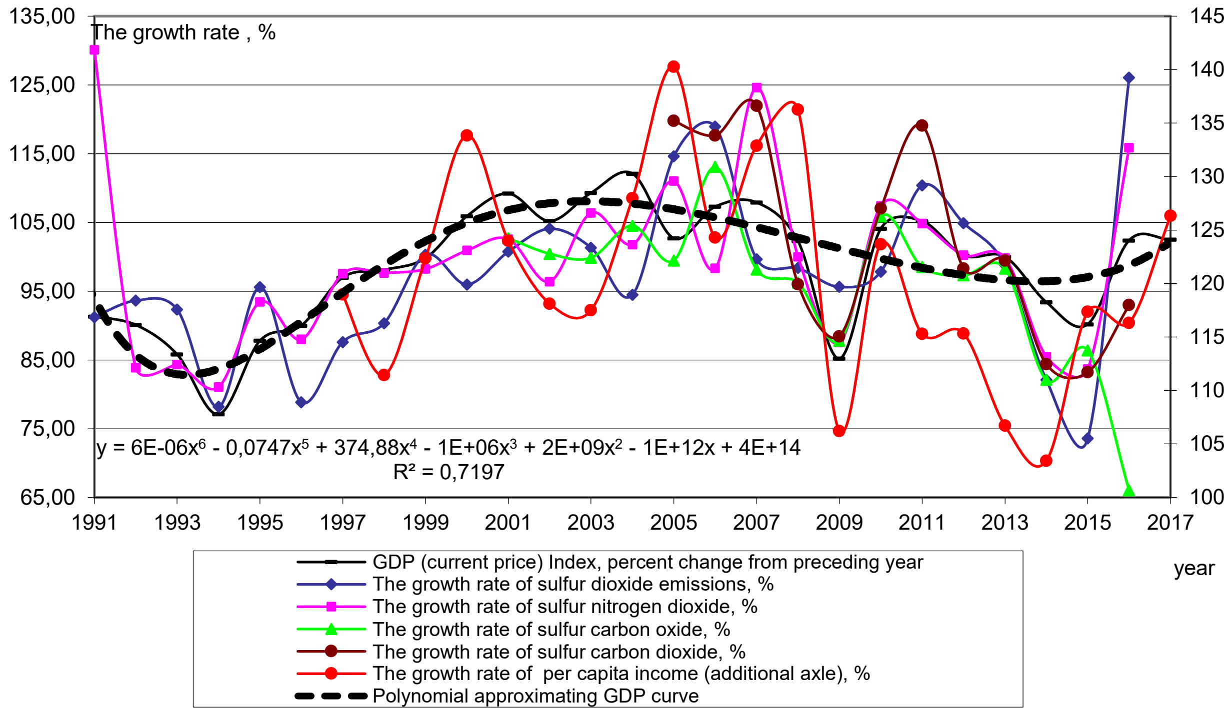

Fig. 1 – Dynamics of GDP indexes, sulfur dioxide, nitrogen dioxide, carbon oxide, carbon dioxide emissions growth chain rates and annual per capita income during 1991–2017

As for the environmental indicators (the volumes of hazardous substances emissions), they also change with some periodicity, but the duration of their cycles is from 2 to 5 years. The maximums and minimums of the curves of sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions growth rates do not always coincide with the corresponding maximums at the curves of GDP indexes and per capita income growth rates.

S. Kuznets proved the existence of the relationship between the hazardous substances emissions volumes and per capita income level, but the traditional EKC is not confirmed by the analysis of official statistic data concerning Ukraine. There is some specificity of this curve, which contains cyclicality, which can be described with the help of distributed lag model.

Most often, when analysing the time series data, it is taken into account that the explanatory variables affect the resulting indicator value at the same moment of time. But, previous value of both the explanatory variables and the indicator itself can affect the current value of the resulting indicator. I.e. the effect from the influence of certain factor on the resulting indicator is manifested not immediately, but gradually, in some period of time. In this case, there appears a time lag.

The changes in one cyclical process can lead to the change in the dynamics of others in some period of time (lag). Lag models are used for studying such processes. In order to substantiate the lags, it is reasonable to use the cross-correlation function, which characterises the density of the relationship of each element of dynamic series of dependent (resulting) y_t and explanatory x_t variables, shifted relative to each other to time lag τ.

In order to substantiate the lags, it is reasonable to use the cross-correlation function, which characterises the density of the relationship of each element of dynamic series of dependent (resulting) y_t and explanatory x_t variables, shifted relative to each other to time lag τ. Cross-correlation coefficient is defined according to the formula:

$$r_\tau = \frac{(n-\tau)\sum_{t-1}^{n-\tau} y_t x_{t-\tau} - \sum_{t-1}^{n-\tau} y_t \sum_{t-1}^{n-\tau} x_{t-\tau}}{\sqrt{[(n-\tau)\sum_{t-1}^{n-\tau} y_t^2 - (\sum_{t=1}^{n-\tau} y_t)^2][(n-\tau)\sum_{t-1}^{n-\tau} x_{t-1}^2 - (\sum_{t=1}^{n-\tau} x_{t-\tau})^2]}} \quad (1)$$

where y_t and x_t are the elements of the vector of dependent (resulting) and explanatory variables, respectively, shifted relative to each other to time lag τ; n is the number of the values of r_τ.

The cross-correlation coefficient changes from –1 to 1, the biggest value on the module defines the shift or time lag. If there are several values, it is thought that the time lag takes place during some period of time, as a result, we have several time lags.

According to the results of comparing the cyclicality of per capita income growth rates, GDP indexes with the dynamics of dependence between the hazardous substances emissions and per capita income and GDP in actual prices, it is found that they do not always coincide. It gives grounds to make a conclusion about the presence of lag between the emissions volumes changes and values of per capita income and GDP in actual prices.

As for current investments, the coincidence of current investments changes dynamics with the hazardous substances emissions should testify the absence of lag and high level of cross-correlation between the mentioned values.

The proposed hypotheses can be checked based on official statistical data.

Figure 2 shows the dynamics of cross-correlation coefficient (correlogram) between the sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions volumes and per capita income during 1996 – 2016.

As for the sulfur dioxide, during 1996–2000, there takes place gradual increase of cross-correlation coefficients values between the hazardous substances emissions and per capita income, maximum absolute value r = 0.9033 was achieved in 2000. The next maximum achieved in 2015 was r = 1.

According to the results obtained (Fig. 1), in 2000, there was observed the increase of per capita income growth rates with the simultaneous minimum of sulfur dioxide emissions growth rates, which absolutely coincides with the results obtained. During past and future years, similar situation was not observed. Thus, it confirms the conclusion that Ukraine did not yet reach a «turning point» in traditional EKC model, only temporary results were obtained.

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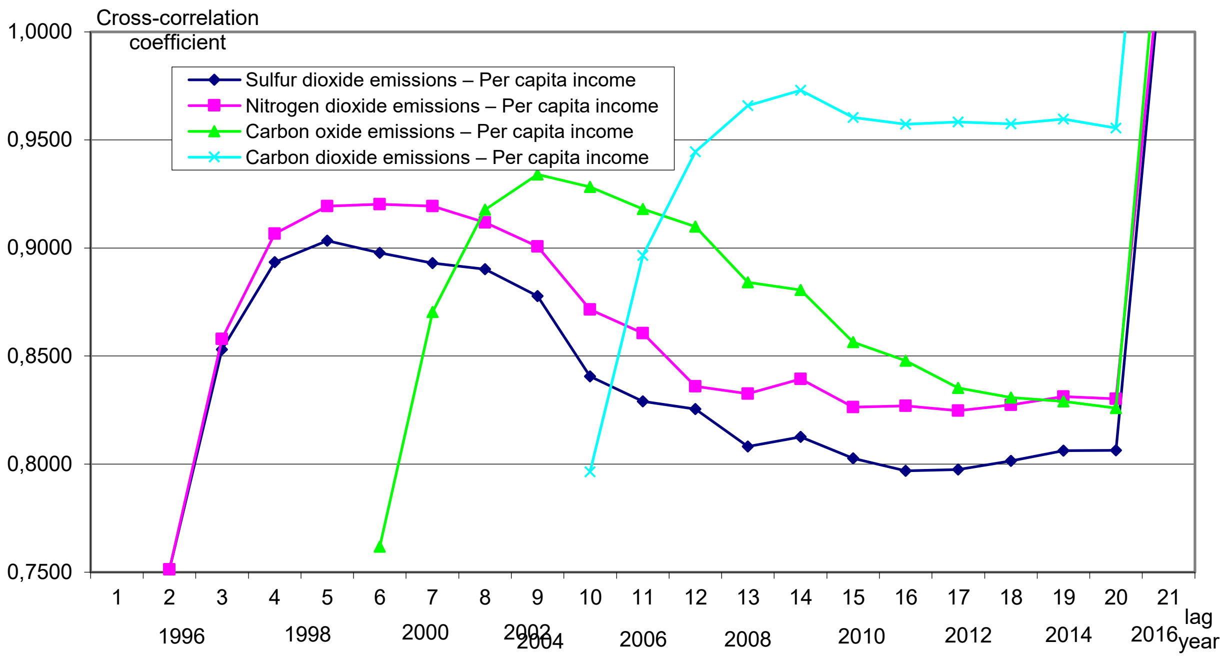

Fig. 2 – Dynamics of cross-correlation coefficient (correlogram) between the sulfur dioxide, nitrogen dioxide, carbon oxide, carbon dioxide emissions volumes and per capita income

As for the nitrogen dioxide, during 1996–2000, there also took place gradual increase of cross-correlation coefficients values between the emissions and per capita income, maximum absolute value $r = 0.9202$ was achieved in 2000. It is close to maximum value ($r = 1$), which shows the presence of high level of values relationship. The next maximum achieved in 2015 was $r = 1$.

The result obtained is also confirmed by the study results (Fig.1): it is in 2000 when there was observed the increase of per capita income growth rates with the simultaneous minimum of nitrogen dioxide emissions growth rates. During past and future years, such coincidence was not found. Thus, similar to sulfur dioxide, it confirms the conclusion that Ukraine did not reach a steady turning point in traditional EKC model. There are temporary, not continuous results.

As for the carbon oxide, during 2000–2004, there also takes place gradual increase of cross-correlation coefficients values between the emissions and per capita income, maximum absolute value $r = 0.9340$ was achieved in 2004. It is close to maximum value ($r = 1$), which shows the presence of high level of values relationship. The next maximum achieved in 2015 was $r = 1$.

It is in 2000 when there was observed the increase of per capita income growth rates with the simultaneous minimum of carbon oxide emissions growth rates (Fig. 1), which absolutely correlated with the data obtained. Thus, similar to sulfur and nitrogen dioxide, it shows that Ukraine did not reach a steady turning point in traditional EKC model, only temporary results were obtained.

Besides, the same time lag value $\tau = 4$ was obtained for all three types of hazardous substances emissions. Thus, it shows that the cyclicality of hazardous substances emissions volumes dynamics differs from cyclicality of per capita income dynamics with the lag of 4 years.

Figure 3 shows the dynamics of cross-country coefficient (correlogram) between the sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide and GDP in actual prices during 1996–2016.

During 1996–2003, there took place the gradual increase of cross-correlation coefficients values between the sulfur dioxide emissions and GDP values, maximum absolute value $r = 0.9007$ was achieved in 2003. It is close to maximum value ($r = 1$), which confirms the presence of high level of values relationship.

Comparing the obtained results concerning the cross-correlation coefficients with the dynamics of GDP growth rates, sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions during 1991–2017 (Figure 1) shows that only in 2003 there was observed GDP indexes growth with the simultaneous minimum of sulfur dioxide growth rates. Thus, it also

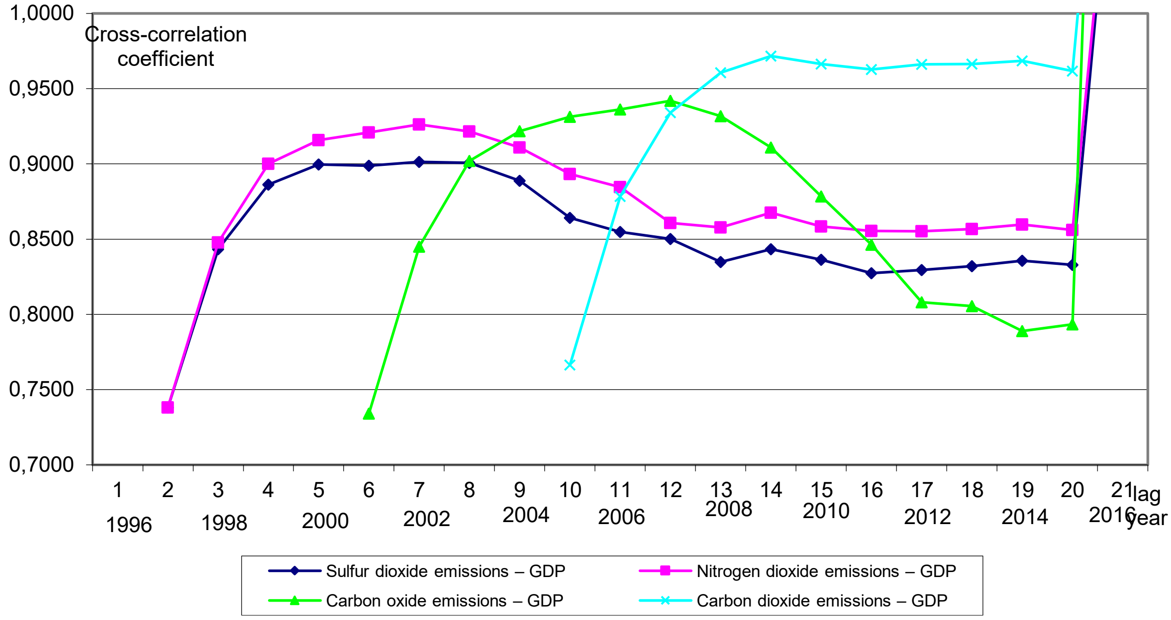

Fig. 3 – Dynamics of cross-correlation coefficient (correlogram) between the sulfur dioxide, nitrogen dioxide, carbon oxide and carbon dioxide emissions volumes and GDP in actual prices

confirms the earlier conclusion about the temporary nature of achieving the turning point at EKC curve.

As for the nitrogen dioxide, during 1996–2003, there also takes place gradual increase of cross-correlation coefficients values between the emissions and GDP values, maximum absolute value r = 0.9216 was achieved in 2003. It is close to maximum value (r = 1), which shows the presence of high level of values relationship.

In 2003, there was observed the increase GDP indexes growth with the simultaneous minimum of nitrogen dioxide emissions growth rates (Figure 1). During past and future years, similar situation was not observed. As it is seen, maximum value of cross-correlation coefficient was achieved. This coincidence confirms the conclusion about the temporary nature of achieving the turning point at EKC curve.

As for the carbon oxide, during 2000–2007, there also takes place gradual increase of cross-correlation coefficients values between the emissions and GDP values, maximum absolute value r = 0.9419 was achieved in 2007. It is close to maximum value (r = 1), that is why it is possible to assume the presence of high level of values relationship. The next maximum achieved in 2016 was r = 1.

Achievement of maximum value of cross-correlation coefficient in 2007 coincided with the with the disclosed tendency towards the GDP index growth with simultaneous minimum of sulfur dioxide and nitrogen dioxide emissions growth rates in 2003 (Figure 1), and the carbon dioxide – in 2007. Thus, similar to relationship between the hazardous substances emissions and per capita income values, the conclusion about the temporary nature of achieving the turning point at EKC curve was confirmed for GDP.

Also it should be noted that the same time lag value τ = 7 was obtained for all three types of hazardous substances emissions. Thus, it is possible to think that the cyclicality of hazardous substances emissions volumes dynamics differs from cyclicality of GDP indexes with the lag of 7 years.

Figure 4 shows the dynamics of cross-correlation coefficient (correlogram) between the sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions volumes and the values of current expenditures on conservation activity during 2000–2016.

The analysis showed that during 2000–2016, there takes place gradual increase of cross-correlation coefficients values between sulfur dioxide emissions and values of current expenditures on conservation activity. It absolutely coincides with the conclusions about the increased effectiveness of financing the measures of environmental protection and their relationship with emissions volumes.

Table 1 analyzes the dynamics of environmental protection expenditure changes.

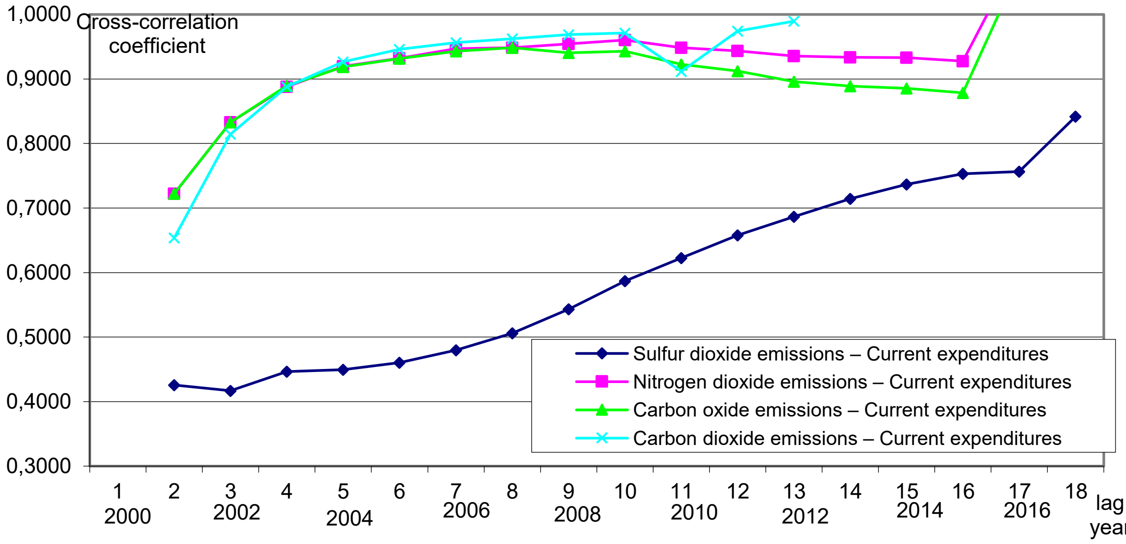

Fig. 4 – Dynamics of cross-correlation coefficient (correlogram) between the sulfur dioxide, nitrogen dioxide, carbon oxide and carbon dioxide emissions volumes and current expenditures

Table 1

Dynamics of budget environmental protection expenditure changes, million UAH

Year	Budget environmental protection expenditure	Growth rate, %	National budget environmental protection expenditure	Growth rate of national budget expenditure, %	Local budgets environmental protection expenditure	Growth rate of local budgets expenditure,%
2007	2241,3		1809,1		432,2	
2008	2764,7	123,35	2230,2	123,28	534,5	123,67
2009	2538,8	91,83	1824,3	81,80	714,5	133,68
2010	2872,4	113,14	2292,7	125,68	579,7	81,13
2011	3890,7	135,45	3008,40	131,22	882,30	152,20
2012	5297,9	136,17	4135,40	137,46	1162,50	131,76
2013	5594,2	105,59	4595,00	111,11	999,20	85,95
2014	3481,7	62,24	2597,00	56,52	884,70	88,54
2015	5529,7	158,82	4053,00	156,06	1476,70	166,92
2016	6255,4	113,12	4771,60	117,73	1483,80	100,48
2017	7349,3	117,49	4739,90	99,34	2609,30	175,85

As one can see, the growth rates of investment are volatile; the slowdown was observed in 2010 - 2013 and 2015, acceleration, on the contrary, in 2009 and 2014. This approach cannot be considered systemic and, as a result, there is lack of radical changes in the environmental situation in the country.

In order to describe the dynamics of the investment, it is possible to propose the model described by the function (2).

The so-called soft one, where the coefficient of investment (ε) depending on the investment:

$$\frac{dN}{dt} = c\,N - d\,N^2. \quad (2)$$

Formula (2) describes the logistic model. We consider that it can be used to describe the process of ecological investment growth. The following expressions for coefficients c and d could be proposed in this model: $c = \varepsilon$, $d = \varepsilon / K$. In this case, the dynamics ecological investment, forming the sufficient level of ecological security, can be described by the logistical equation:

$$\frac{dN}{dt} = \varepsilon N - \frac{\varepsilon}{K} N^2, \quad (3)$$

where ε – constant coefficient of proportionality which is the ratio of the ecological investment growth rate $\frac{dN}{dt}$ to the volume of ecological investment N;

$K = N_{max}$ – maximum possible and safe rate of ecological investment.

In this model, steady state C is sustainable: higher income – decreases, lower – increases.

The equation (3) can be written in another way:

$$\frac{dN}{dt} = \varepsilon N \frac{K-N}{K} . \quad (4)$$

Dividing the variables into equation (4), we obtain:

$$\frac{KdN}{N(K-N)} = \varepsilon dt . \quad (5)$$

Taking into account that

$$\frac{1}{N(K-N)} = \frac{1}{KN} + \frac{1}{K(K-N)} , \quad (6)$$

the equation (5) will be:

$$\left(\frac{1}{N} + \frac{1}{K-N}\right) dN = \varepsilon dt . \quad (7)$$

After integration (7), we obtain:

$$\int \left(\frac{1}{N} + \frac{1}{K-N}\right) dN = \int \varepsilon dt + A ,$$

ln T – ln(K - T) = ε t + ln a, ln a = A,

$$\ln \frac{N}{K-N} = \varepsilon t + \ln a . \quad (8)$$

From the equation (8) we find:

$$\frac{N}{K-N} = a\, e^{\varepsilon t} . \quad (9)$$

When t = 0, the amount of ecological investment is R = R_0 , then from the equation (9) we obtain:

$$a = \frac{N_0}{K - N_0} .$$

Having solved the equation (8) as to N, we find the function *N = f (t)* in this form:

$$N(t) = \frac{aK\, e^{\varepsilon t}}{1 + a\, e^{\varepsilon t}} . \quad (10)$$

If to divide the numerator and denominator of the right part by e^{rt}, we obtain:

$$N(t) = \frac{aK}{a + e^{\varepsilon t}} , a = \frac{N_0}{K - N_0} , 0 < a < \infty . \quad (11)$$

Function (11) can be presented as:

$$N(t) = \frac{K}{1 + \exp(b - \varepsilon t)} , \quad (12)$$

where constant of integration *b*:

$$b = \ln \frac{1}{a} = \ln \frac{K - N_0}{N_0} . \quad (13)$$

The traditional model of the studied dynamics of process` development is: $\frac{dN}{dt} = \varepsilon N$, parametric variable ε – specific speed of ecological investment is considered to be constant. To take into account the inverse relationship in the economic system, we assume that *r(R)* is variable, which depends on income:

$$r(R) = b - aR = r_0 - \frac{r_0 R}{K} .$$

It is under these conditions we have a logistic model of the rate of return changes` dynamics:

$$\frac{dN}{dt} = \varepsilon(N)N = (b - aN)N = \varepsilon_0 (1 - \frac{N}{K})N, .$$

$$K = N_{\max}, b = \varepsilon_0, a = \frac{\varepsilon_0}{K}$$

The equation (5) could be presented as:

$$N(t) = \frac{a}{1 + b e^{\varepsilon t}} \qquad N(t) = \frac{1}{a b^t + \eta}$$

The upper point of the logistical curve is defined as $\frac{1}{\varepsilon}$; the lower point as – $\frac{1}{a+\varepsilon}$; point of trajectory inflexion – $\frac{1}{2\varepsilon}$.

In our opinion, the logistic equation can be considered an equation that is closest to the conditions of ecological investment sustainable development. Thus, it allows to determine safe limits of ecological investment changes, which is capable to ensure sustainable development. The lower and upper points of the curve`s trajectory are these limits.

Thus, the expedient of developing the agreed policy concerning the economic (GDP value), social (population income level) and environmental components (conservation activity financing and decrease of hazardous substances emissions) taking into account the time lag, which will create the conditions for achieving not only temporary values, but also long-term parameters of EKC curve in the Ukrainian economy, was substantiated.

Conclusions

Based on the analysis of GDP growth rates dynamics, sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions during 1991–2017, the periodicity (cyclicality) of their change lasting from 3 to 5 years was proved.

According the results of the study on the relationship between the per capita income in Ukraine and sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions volumes during 1991–2017, it was found that Ukraine did not reach a steady turning point, which is present in traditional EKC model. The cyclicality concerning the dynamics of the mentioned indicators change lasting from 3 to 5 years (small cycles) was proved.

Against the background of the analysis of the relationship between the GDP in actual prices and sulfur dioxide, nitrogen dioxide, carbon oxide and dioxide emissions volumes during 1996–2017, it was proved that in Ukraine, EKC on GDP has a specific nature, which is caused by significant dependence of the environmental development indicators based on the hazardous substances emissions criterion from the level of economic development.

The hypothesis about the need to take into account the indicators of conservation activity investment in EKC against the background of the analysis of the dynamics of the relationship between current and capital expenditures on conservation activity and volumes of sulfur dioxide, nitrogen dioxide, carbon oxide emissions during 2000–2017 was confirmed. The presence of periodicity (cyclicality) of the processes lasting from 3 to 5 years was found.

In Ukraine, EKC has a specific nature in the form of separate "turning points", without achievement of long-term parameters of the relationship between the hazardous substances emissions and GDP and per capita income values.

Thus, the feasibility of developing the agreed policy concerning the economic (GDP value), social (population income level) and environmental components (conservation activity financing and decrease of hazardous substances emissions) taking into account the time lag, which will create the conditions for achieving not only temporary values, but also long-term parameters of EKC curve in the Ukrainian economy, was substantiated.

Conflict of interests

The authors declare that this article is made within the research 0120U102208 "Multicriteria management of sustainable development of natural economic systems" (Стаття виконана у межах НДР 0120U102208 «Багатокритеріальне управління сталим розвитком природно-господарських систем»). In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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