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# DYNAMIC MODEL OF THE ECONOMY IN THE CONDITIONS OF ECOLOGIZATION OF PRODUCTION AND CONSUMPTION PROCESSES

***Mariia Hryhorkiv*[1], *Vasyl Hryhorkiv*[2], *Lesia Buiak*[3], *Anna Pavlovska*[4], *Ivan Gaidutskyi*[5], *Yuliia Khoroshun*[6]**

[1] *Dr. Prof., Yuriy Fedkovych Chernivtsi National University, 2 Kotsyubynsky Str., Chernivtsi, Ukraine, E-mail address: m.hryhorkiv@chnu.edu.ua*

[2] *Dr. Prof., Yuriy Fedkovych Chernivtsi National University, 2 Kotsyubynsky Str., Chernivtsi, Ukraine, E-mail address: v.hryhorkiv@chnu.edu.ua*

[3] *Dr. Prof., West Ukrainian National University, 11 Lvivska st., Ternopil, Ukraine, E-mail address: l.buiak@wunu.edu.ua*

[4] *Dr. Prof., Cherkasy State Technological University, 460 blvd. Shevchenko, Cherkasy, Ukraine, E-mail address: annasuray0@gmail.com*

[5] *Dr. Prof., National Technical University of Ukraine, 37 Prospect Beresteiskyi, Kyiv, Ukraine, E-mail address: ivan.gaid@gmail.com*

[6] *PhD Student, Cherkasy State Technological University, 460 blvd. Shevchenko, Cherkasy, Ukraine, E-mail address: july230181@gmail.com*

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**Abstract**

The need for greening the modern economy and developing the ecological economy in the future, in which production and consumption processes would be ecologically and socially balanced, is substantiated. Taking into account that ecological and economic systems belong to complex objects of research, the relevance of improving existing and developing new methodologies for their study, in particular development of modeling, which in combination with modern information technologies, has wide opportunities for the study of such objects, is emphasized. The dynamic model of the economy has been developed, under the conditions of environmentalization of production and consumption, which is formalized in the space of ecological and economic variables, taking into account the socio-economic clustering of society. Conceptually, the model is built in such a way that a number of modified models can be offered on its basis. Models of this class are intended for qualitative and quantitative analyzes of the processes of ecological and economic interaction that take place in the studied economy. Simulation experiments with such models make it possible to obtain fundamentally important results regarding the behavior of ecological-economic systems, in particular, to identify general patterns and trends in the development of the economy in the conditions of its environmentalization, which serves as a valuable information base for the development of possible scenarios of ecological-economic development and support for making managerial decisions regarding improvement of the ecological and economic situation in real practice.

***Keywords***: *ecological economy, volume of savings, purchasing power, tariff, model, ecological and economic dynamics.*

***JEL Codes***: *C610, C630, E270.*

## Introduction

The second half of the 20th and the beginning of the 21st century became, in a certain sense, a turning point in the formulation and understanding of the problems of environmentalization of the economy and human life as a whole. The advanced part of humanity, in particular scientists, government and public figures, are increasingly raising the issues about existing environmental crises (climate change, floods, droughts) on the regional and global scale, irrational use of nature, environmentally harmful technologies of production and consumption, and other negative phenomena and processes, the cause of which there is the anthropogenic factor. Therefore, the need to build a new model of the economy or the so-called economy of sustainable (supportable) development has become particularly acute and urgent. However, it is impossible to build such a model without ecologization of the economy, therefore, ecologization of the economy is an irreversible process, which implementation will allow preserving the environment suitable for the life of future generations of people. The problem of greening the economy is complex and includes a set of measures, algorithms, mechanisms, environmental standards, etc., which require deep scientific justification, informational and financial support and, what is extremely important, the development of environmental education and formation of environmental culture in society. The humanitarian aspect of the problem of greening is significantly related to the greening of production and consumption, because in the ecologically educated society, the attitude of people to nature and their living space is more adequate and moral.

Therefore, the problem of building the ecological economy today belongs to the priority objects of scientific knowledge. At the same time, one of the most effective methods of its research is the modeling method, in particular economic-mathematical modeling, the possibilities of which have significantly expanded today thanks to modern computer and information technologies. The fact is that computer simulation with models of economic and ecological-economic systems allows identifying such features and scenarios of the development of those systems that cannot be investigated by classical analytical tools, which is a significant result for the economic theory and practice. These models include the model of ecological and economic dynamics, to which this paper is devoted.

The purpose of the article is to build a general dynamic model of the ecological economy, in which the processes of greening production and consumption are mandatory for its balanced functioning. At the same time, it is worth noting that the dynamics of ecological and economic systems always has its own characteristics, which significantly depend on the factors influencing the external environment, the structure of systems, the level of aggregation, the choice of the modeling space (phase space), etc., which actually reflect the dynamics models.

## Literature review

The scientific-research platform for studying the processes of the ecological-economic interaction, in particular the dynamics of ecological-economic systems, was originally formed in the second half of the 20th century in the works of J. Forrester (1971), D. Meadows (1972), E. Pestel (1974) and other world-class scientists. The ideas, concepts, and models proposed by these and other scientists subsequently had a fundamental impact on research in modeling of ecological and economic systems by a whole galaxy of foreign and domestic scientists who, continuing the study of the classics, developed a considerable number of models, methods and algorithms, which today constitute a powerful methodological base for further scientific research in the direction of modeling ecological and economic processes and systems and preparation and decision-making regarding their effective management. At the same time, in addition to static ecological and economic models (balance, optimization), the researchers proposed different levels of aggregation of the models of ecological and economic dynamics, substantiated the possibilities of their qualitative analysis and practical application.

Current studies of economic systems (O. Hetman et al. (2019), O. Iermakova et al. (2019), A. Zhavoronok et al. (2022), Marhasova et al. (2024)) have proven that the economy is a complex, dynamic, developing or evolutionary system. In turn, the works of many scientists, including Z. Huang (2007), A. Abramova (2021) and others, also played an important role in the study of the problems of ecological and economic interaction in the context of the development of relevant models and methods. Considering the relevance of the subject of research, it can be said that such research has a reliable perspective.

However, unlike many known models of ecological and economic dynamics, this study uses ecological and economic indicators (variables) that describe not only economic and ecological, but also social factors, since ecological and economic dynamics are studied

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taking into account the socio-economic clustering of society.

In addition, the task is to reflect the dynamics of the environmental pollution in the model, which formalization allows taking control over this pollution, especially over that part of it that is created in the processes of production and consumption of the main aggregated product. Development of the model proposed below is also relevant in the sense that indicators of the state of the modeling object or dynamic variables of the model form an admissible set of trajectories of ecological and economic dynamics, among which, using appropriate parameters and functions, you can choose those that most adequately reproduce real processes, occurring in the studied economy. We would also like to emphasize that the current conceptual and methodological aspects are laid down in this study, which will have ample opportunities for expansion and improvement in the process of building and applying the models of the proposed class.

## Methodical approach

The methodological basis of this study is construction of the economic-mathematical model of the dynamics of the object under study with possible introduction of various factors depending on the choice of variables. Based on the developed model, it is possible to determine the dynamic change of the indicator depending on time and make its forecast for the future.

## Results

In the following article, we will talk about the economy, which we will consider to be one-sector, that is, one in which, on the one hand, production of the main aggregated product (AAP) is realized, and, on the other, disposal of the pollution created during the production and consumption of AAP. We will also assume that direct creators of this economy are M owners of factories or producers and N employees (workers and all other specialists involved in the functioning of the economy), and the employees of each of these clusters are considered equal within their cluster (such averaging makes sense when studying the main trends in the dynamics of the ecological economy).

Models of the dynamics of the studied economy can be built in different phase spaces depending on the choice of variables that actually form this space. Let's specify the spatial variables that will be used below.

Therefore, by $z_M$ and $z_N$ we denote, respectively, the liquid savings (in the future, we will only use the term "savings" for abbreviation) of an individual owner of production and an employee, and by $p$, $\tilde{p}$ and $z$ - the price of OAP, the tariff for the disposal of pollution products (PP) and the amount of environmental pollution, respectively, in including those remnants of production and consumption that are not disposed of and thrown into the environment.

Having formalized the dynamics of these variables, we will really describe the model of ecological and economic dynamics, therefore we will deal with the formalization of the model.

The volumes of the OAP consumption depend on the demand for it. Let the demand be described by the demand function $q(s)$, where $s$ is the purchasing power of the consumer.

If we consider that $\alpha$ and $\tilde{\alpha}$ $(0 \le \alpha, \tilde{\alpha} \le 1)$ - shares of the owner's and employee's savings spent on OAP, $s_\alpha = \dfrac{\alpha z_M}{p}$ and $s_{\tilde{\alpha}} = \dfrac{\tilde{\alpha} z_N}{p}$ - their purchasing power.

Both OAP production and consumption is connected with the generation of certain wastes and the demand for their disposal. It is logical to assume that the emission function of pollution, which is formed as a result of the OAP consumption also depends on the purchasing power of the consumer. We denote this function by $f_c$.

But the demand for waste disposal (production or consumption) does not always coincide with their output, so let $q_c$ - the demand function for waste disposal from the OAP consumption.

At the same time, it can be assumed that there is also a certain functional dependence between the functions $f_c$ and $q_c$, since both functions in one way or another depend on the purchasing power of the consumer of the corresponding cluster. The income of an employee in production is determined by his salary $d_N$. Denoting through $\pi_0$ the income tax rate and using the above notations and assumptions, the equation of the savings dynamics of the above-mentioned employee can be described in the form:

$$\frac{dz_n}{dt} = d_N(1-\pi_0) - pq(s_{\tilde{\alpha}}) - \tilde{p}q_c(s_{\tilde{\alpha}}). \qquad (1)$$

The equation for the dynamic variable will have a more complex structure - $z_M$. To describe it, it is still necessary to make a number of clarifications regarding formation of income and expenses of the owner of productions. Of course, his income (taking into account taxation) depends on the volume of the OAP demand of all owners and production workers and the volume of their demand for disposal of waste from the OAP consumption, as well as on the volume of the OAP demand of other parts of society, the state, business, etc. (this volume will be denoted through $Q_1$) and the volume of waste disposal (hereinafter $Q_3$) from the consumption $Q_1$ of units (units) of OAP (the volume of software release after consumption $Q_1$ of OAP units is denoted by $Q_2$ ).

Now let's detail the costs. We will assume that $\beta$, $\gamma$ $(0 \le \beta, \gamma \le 1, \alpha + \beta + \gamma \le 1)$ - shares of the savings of the production owner for the OAP release and disposal of the software of production and consumption processes.

Then:

$-s_\beta = \dfrac{\beta z_M}{p}$ – production capacity of the owner of the OAP production;

$-s_\gamma = \dfrac{\gamma z_M}{p}$ - ability of the owner to dispose of pollution.

The volume of production pollution release is described by the function $\varphi$, which also depends on $s_\beta$, that is $\varphi = \varphi(s_\beta)$, and the volume of disposal is the function $\psi = \psi(s_\gamma)$. Therefore, the costs of the owner's production are related to the personal demand for OAP, the demand for disposal of waste from the OAP consumption, wages and salaries of employees and tax on the payroll fund (rate $\pi_1$ ), organizational needs for the OAP production ( $\lambda_\beta$ - share of costs) and the value added tax (rate $\pi_2$), organizational needs regarding disposal activities ( $\lambda_\gamma$ – share of costs) and environmental tax (rate $\pi_3$). Taking into account the above-described structure of income and expenses of the production owner, the equation of the dynamics of his savings can be formalized as follows:

$$\frac{dz_M}{dt} = \frac{p(1-\pi_0)}{M}[Mq(s_\alpha) + Nq(s_{\tilde{\alpha}}) + Q_1] + \frac{\tilde{p}(1-\pi_0)}{M} \times [Mq_c(s_\alpha) + Nq_c(s_{\tilde{\alpha}}) + Q_3] - pq(s_\alpha) - \tilde{p}q_c(s_\alpha) - \frac{Nd_N(1+\pi_1)}{M} - p(\lambda_\beta + \pi_2)f(s_\beta) - \tilde{p}(\lambda_\gamma + \pi_3)\psi(s_\gamma) \qquad (2)$$

As for the change in time of the OAP price, this change depends on the difference between the demand for OAP and its supply, therefore:

$$\frac{dp}{dt} = \theta_\beta\left[Mq(s_\alpha) + Nq(s_{\tilde{\alpha}}) + Q_1 - Mf(s_\beta)\right]. \qquad (3)$$

The equation $\theta_\beta$ (3) refers to the price regulation coefficient, which role is to formalize the inertia of the OAP market.

The equation of the dynamics of the disposal tariff is modeled in a similar way, but the demand for the disposal of industrial pollution depends significantly on the producer himself, who is actually the culprit of the pollution. In the ideal situation, the manufacturer should completely dispose of the pollution it creates, but usually this is not the case. Manufacturers try to hide the real volumes of pollution or dispose of only a small part of it. In this regard, the state and non-governmental organizations should have strict control over compliance with established environmental production standards. This control can be described by a minimally defined fraction (let $k_\varphi$ $(0 \le k_\varphi \le 1)$ - the specified share) of industrial pollution, which must be disposed of and which is actually the manufacturer's guaranteed demand for

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disposal. Given this circumstance, the tariff dynamics equation will take shape

$$\frac{d\tilde{p}}{dt}=\theta_{\gamma}\left[Mk_{\varphi}\varphi(s_{\beta})+Mq_{c}(s_{\alpha})+Nq_{c}(s_{\tilde{\alpha}})+Q_{3}-M\psi(s_{\gamma})\right], \quad (4)$$

where $\theta_{\gamma}$ is the regulation coefficient of the disposal tariff.

We still need to simulate the dynamics equation for the variable $z$, that is, for the amount of environmental pollution. It is obvious that the growth of such pollution is determined by the difference between the pollution created as a result of production and consumption and the pollution eliminated as a result of disposal and natural self-cleaning. Therefore, under the conditions of the accepted assumptions and notations, the equation for the dynamic variable $z$ will be as follows:

$$\frac{dz}{dt}=M\varphi(s_{\beta})+Mf_{c}(s_{\alpha})+Nf_{c}(s_{\tilde{\alpha}})+Q_{2}-M\psi(s_{\gamma})-\mu z. \quad (5)$$

In equation (5) $\mu$ is the coefficient of natural self-cleaning, which reflects the ability of the natural environment to self-clean $(0\leq\mu\leq1)$.

The combination of equations (1) - (5) formalizes one of the possible differential models of the economy, taking into account the environmentalization of production and consumption processes. Of course, to find a unique solution, the system of equations (1) - (5) needs to be supplemented with initial conditions:

$$\begin{cases} z_{M}(t_{0})=z_{M}^{(0)}, z_{N}(t_{0})=z_{N}^{(0)}, \\ p(t_{0})=p^{(0)}, \tilde{p}(t_{0})=\tilde{p}^{(0)}, z(t_{0})=z^{(0)}. \end{cases} \quad (6)$$

The values $t_{0}, z_{M}^{(0)}, z_{N}^{(0)}, \tilde{p}^{(0)}, z^{(0)}$ in equation (6) are considered given.

The ratios of equations (1) - (6) reproduce the concept of building a general model of the ecological economy. Based on them, it is possible to formalize a number of more specific models of the economy, for which the greening of production and consumption is a necessary condition for its functioning.

Current level of development of the theory of differential models and corresponding software of methods of finding their solutions allow to simulate the behavior of ecological and economic systems and processes related to them, if adequate information support is available. For example, based on the test data, in Fig. 1-4, possible trajectories $z_{M}(t), z_{N}(t), p(t), \tilde{p}(t)$ for the time interval t are presented and their dependence on certain parameters is analysed. In other words, the conceptual approach proposed above to building a model of ecological and economic dynamics has obvious applied significance.

Based on the proposed models, we will graphically plot the dynamics of liquid savings of producers and consumers during the period of time t (Fig. 1, 2).

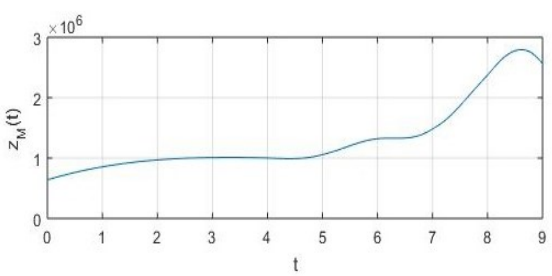


**Figure 1. Dynamic change in the volume of producer savings during the period,** $z_{M}(t)$

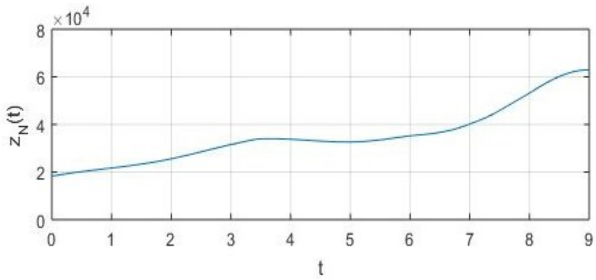


**Figure 2. Dynamic changes in the amount of employee savings during the period,** $z_{N}(t)$

So Fig. 1, 2 illustrate the dynamic change in the amount of producer's and employee's savings over a certain period. Dependence of the amount of savings of the producer and the employee on time is not linear, since the lines on the graph have several maxima and minima, which indicates fluctuations or changes in the rate of growth or decline at different points in time, although on average the dynamics reflect the growth of the amount of savings with the flow time This dependence can be used to predict values for the future.

In Fig. 3, 4 we will plot the dynamic change in the price of the main aggregated product $p(t)$ and the tariff for disposal of pollution products $\tilde{p}(t)$ for a period of time t.

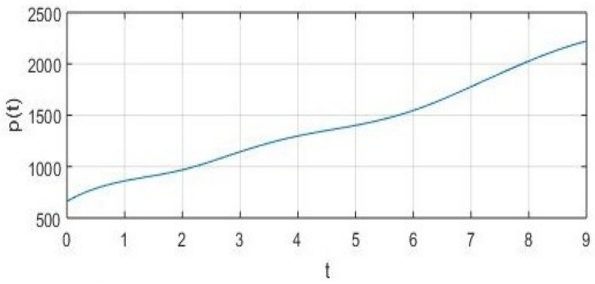


**Figure 3. Dynamic change in the OAP price for the period, $p(t)$**

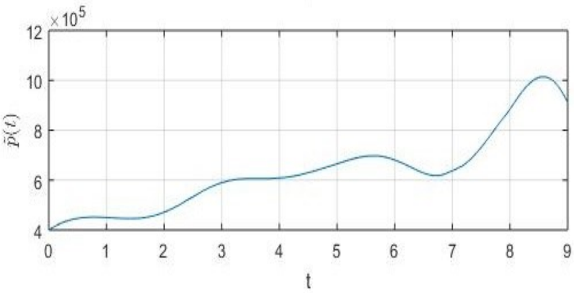


**Figure 4. Dynamic change of the software disposal tariff for the period, $\tilde{p}(t)$**

So Fig. 3, 4 illustrate the dynamic change of the OAP price and the software disposal tariff for a certain period. The dependence of the volume of the OAP price and the software disposal tariff on time is not linear, although the dynamics reflect the growth of these indicators over time. This dependence can be used to predict values for the future.

The modified refinements of the model (1) - (6) are first of all related to the specification of its parameters, which can be both constant and time-dependent values, as well as classes of the corresponding functions of demand, output and utilization. In addition, assumptions about the volume of the OAP demand, the volume of pollution products as a result of its consumption, and the demand for the disposal of this pollution in that part of society that is not directly involved in production are of important applied value.

## Conclusions

The results obtained in this study are relevant in both theoretical and applied contexts. Their theoretical significance lies in the disclosure and formalization of the methodology for modeling the dynamics of ecological and economic variables, taking into account socio-economic clustering of society. The proposed dynamic model of the economy in terms of environmentalization of production and consumption processes can become a basic model for the development of similar, but more specific models. As for the applied aspect of the research results, it is related to the generally recognized relevance of dynamics models as a toolkit for qualitative and quantitative analysis of the processes of ecological and economic interaction with the aim of building the ecological economy. Based on the proposed class of models in the mode of computer simulation, it is possible to study the main characteristics, regularities, trends and peculiarities of ecological and economic dynamics, to evaluate the ecological norms of production and consumption in the modern economy, to determine its equilibrium states and their nature, as well as other issues that are important for greening the economy. Theoretical and applied results obtained on the basis of research are fundamentally important and valuable for preparation and decision-making in the processes of management of ecological and economic systems. As for the identification of such models, this problem is of independent importance and requires a separate theoretical and applied justification.

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