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# NORDHAUS MODEL AND ENVIRONMENTAL FACTORS IN SUSTAINABLE DEVELOPMENT IN UKRAINE

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# МОДЕЛЬ НОРДХАУЗА ТА ЕКОЛОГІЧНІ ФАКТОРИ У СТАЛОМУ РОЗВИТКУ УКРАЇНИ

*This article explores the Nordhaus Model, considering the crucial aspect of environmental factors and applying it to Ukraine. The Nordhaus Model, developed by economist William Nordhaus, has become an important tool for analyzing the relationship between economic development and sustainable ecological practices. The article emphasizes the relevance of the interaction between the economy and ecology, particularly in Ukraine. The author provides a detailed examination of the*

*key aspects of the Nordhaus Model and its applicability in analyzing the impact of environmental factors on economic development. The article investigates the influence of environmental considerations on Ukraine's economic development, especially in the context of reducing environmental pollution and preserving natural resources. The author thoroughly analyzes the correlation between economic indicators and the state of the environment in Ukraine. The Nordhaus Model is employed to forecast potential scenarios of economic development where the balanced integration of economic and environmental factors is a significant challenge. The research results indicate the necessity of developing and implementing strategies aimed at ensuring sustainable development and minimizing the impact of economic activities on the environment. The article also offers specific recommendations for the Ukrainian government and other stakeholders concerning the development of effective policies aimed at improving the quality of life for citizens and preserving natural resources. The article underscores the importance of developing balanced strategies that help conserve natural resources and minimize the adverse impact on the environment while ensuring economic development. The author calls for the integration of environmental aspects into economic policies and the development of specific recommendations for the Ukrainian government and the business community. This article is of great significance to policymakers, researchers, and citizens interested in environmental conservation and sustainable economic development in Ukraine. It contributes to further discussions and research in this vital area.*

*Дана стаття розглядає Модель Нордхауза, враховуючи важливий аспект сучасності – екологічні фактори, і застосовується для України. Модель Нордхауза, розроблена економістом Вільямом Нордхаузом, вже стала важливим інструментом для аналізу інтервалу між економічним розвитком та сталим забезпеченням екологічної стійкості. У статті вказано про актуальність проблеми взаємодії економіки та екології, зокрема в Україні. Автор детально розглядає основні аспекти Моделі Нордхауза та її можливості застосування для аналізу впливу екологічних факторів на*

*економічний розвиток. Стаття досліджує вплив екологічних аспектів на економічний розвиток України, зокрема в контексті зменшення забруднення довкілля та збереження природних ресурсів. Автор ретельно аналізує взаємозв'язок між економічними показниками та станом навколишнього середовища в Україні. Автор використовує Модель Нордхауза для прогнозування можливих сценаріїв економічного розвитку, де збалансоване поєднання економічних та екологічних факторів виступає важливим завданням. Результати дослідження вказують на необхідність розробки та впровадження стратегій, які б забезпечували сталий розвиток та зменшення впливу господарської діяльності на навколишнє середовище. В цій статті також надаються конкретні рекомендації для уряду та інших зацікавлених сторін щодо розвитку ефективних політик, спрямованих на покращення якості життя громадян та збереження природних ресурсів. У статті підкреслено важливість розвитку стратегій, які б допомагали зберегти природні ресурси та мінімізувати негативний вплив на навколишнє середовище, одночасно забезпечуючи економічний розвиток. Автор закликає у статті до інтеграції екологічних аспектів у економічну політику та розробки конкретних рекомендацій для українського уряду та бізнес-середовища. Дана стаття має важливе значення для урядовців, науковців, та громадян, які цікавляться збереженням навколишнього середовища та сталим економічним розвитком в Україні, сприяє подальшим обговоренням та дослідженням у цьому важливому напрямі.*

***Ключові слова:*** *модель Нордхауза, екологічні фактори розвитку, навколишнє середовище, сталий розвиток*

***Keywords:*** *Nordhaus model, environmental development factors, environment, sustainable development.*

**Statement of the problem in general view and its connection with important scientific and practical tasks.** At the present stage, economic development and environmental preservation have become extremely crucial for

many countries, especially for Ukraine. Alongside the goals of achieving economic stability and GDP growth, there is a need to ensure ecological sustainability and reduce the impact of economic processes on the environment. The issue of natural resource depletion and environmental pollution is both scientifically grounded and practically significant, especially after the end of the war. The Nordhaus Model can be used to determine optimal economic strategies that allow the preservation of resources and the reduction of emissions of pollutants. The increasing levels of air, water, and soil pollution have a negative impact on the health and quality of life of the population. Climate change is a global problem, and Ukraine is also facing its consequences. Balancing economic growth with environmental constraints is a critical task.

**Analysis of latest research and publications.** Recent research and publications have highlighted the importance of the Nordhaus Model in addressing these challenges. Nobel Laureate William Nordhaus developed the Dynamic Integrated Climate-Economy (DICE) model, which allows the assessment of the costs and benefits of climate change mitigation measures. This model was used in the development of the Kyoto Protocol (1997), an international agreement aimed at limiting emissions of greenhouse gases [1, 2].

Authors T.V. Merkulova and O.V. Tomilovych described a macroeconomic dynamic model that incorporates environmental factors based on a modification of William Nordhaus's dynamic integrated climate-economy model, focusing on the case of Ukraine [3].

O. Yu. Lebid constructed econometric models for analyzing and forecasting the investment climate in Ukraine in his work [4].

A.V. Shevchuk elaborated on a new concept of spatial economic-technological development for Ukraine, emphasizing the advantages of concentrating intellectual, information, and other resources to activate high-tech economic sectors [5].

Even in the "favorable" years before the war, it was evident that Ukraine's economic development was oriented toward resource-intensive industries [15]. The correlation between indicators of overall economic performance, the level of business innovation, and scientific activity suggests that economic growth, as measured by

GDP per capita, lags the levels of innovation-active enterprises and scientific and technological activities [16]. Continuing such a course during a crisis is unacceptable. To stimulate innovation and scientific-technical development at a high level, advanced strategic management measures aimed at the systematic development of specific territorial socio-economic systems should be implemented. This pertains to well-developed territories that should be attractive for investments in innovation due to various privileges and incentives [6, 7].

**Formulation of the goals of the article**. The main objectives of this article are to examine the impact of environmental factors on the processes of economic growth and indicators of sustainable development in Ukraine within the context of the Nordhaus Model. It also involves conducting an analysis of possible strategies and policies that promote a balance between economic development and environmental protection in Ukraine.

**Presentation of the main research material.** The Nordhaus Model is like a prism through which economists view economic development and its impact on the environment. This model serves as a reminder that economic growth must be balanced because every dollar of economic gain can have its cost in ecological terms. According to the fundamental principles of the Nordhaus model, a modified macroeconomic dynamic model has been developed, considering environmental factors. This model includes equations that describe these dependencies. In this article, I used formulas from the work of Nordhaus [2] and T.V. Merkulova and O.V. Tomilovych [3].

The final output is reduced by the costs associated with climate and environmental impacts.

$$Q(t)=Y(t) - TC(t),$$

Q(t) – net product, Y(t) – Gross Domestic Product, TC(t) – costs of air protection and climate change issues. Calculations are presented in Table 1.

**Table 1. Net final product with deduction of climate-related costs in Ukraine in the period 2016-2020.**

| Indexes | Years | | | | |
|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2019 | 2020 |
| Costs for atmospheric air protection and climate change problems, million hryvnias | 4263,4192 | 4712,3017 | 6403,5926 | 7240,6567 | 7971,1122 |
| GDP, million hryvnias | 2385367 | 2983882 | 3 560 596 | 3978400,33 | 4222026 |
| Net final product, UAH million | 2381103,58 | 2979169,698 | 3554192,407 | 3971159,68 | 4214054,888 |

*Source: compiled by the author based on sources [8,9].*

Let's make some observations based on the data:

1. Expenditures on air pollution control and climate change issues increased during the period under review. From 2016 to 2020, they rose from 4,263.4192 million UAH to 7,971.1122 million UAH. This indicates a growing focus on environmental issues and climate change in Ukraine.

2. GDP also showed growth dynamics during the period from 2016 to 2020. It increased from 2,385,367 million UAH in 2016 to 4,222,026 million UAH in 2020. This reflects the overall economic development of the country.

3. Net final product (NFP) also exhibited growth during the period from 2016 to 2020. It increased from 2,381,103.58 million UAH in 2016 to 4,214,054.888 million UAH in 2020. This indicates that the production of goods and services was growing faster than expenditures on air pollution control and climate change issues.

4. Expenditures on air pollution control and climate change constitute a small percentage of GDP. For example, in 2016, this indicator accounted for 0.18% of GDP, and in 2020, it was 0.19%. This may indicate the need for more financial support and investments in climate protection measures to achieve more significant results.

5. The increase in expenditures on air pollution control and climate change issues may be related to the heightened awareness of environmental problems and the growing recognition of their importance for the country's sustainable development.

It is the net final product Q(t) that is used for consumption and saving.

$$Q(t)=C(t)+I(t),$$

C(t)=(1-s)Q(t) – final consumption, I(t)=sQ(t) – Capital Investments, 1-s and s – a fixed rate of consumption and savings, respectively. Calculations are presented in Table 2.

According to the table, the following conclusions can be drawn about the net final product for consumption and savings in Ukraine in the period from 2016 to 2020:

1. Capital investment: The value of capital investment increased throughout the period from 2016 to 2020. Starting with UAH 2,502.81 million in 2016, they increased to UAH 5,595.32 million in 2020. This indicates the growth of investment activity in the economy of Ukraine.

2. Final consumption: Total final consumption also increased during the period under review. From UAH 2,378,600.78 million in 2016 to UAH 4,208,459.57 million in 2020. This indicates an increase in the level of consumer activity in the country.

**Table 2. Net final product for consumption and savings in Ukraine in the period 2016-2020.**

| Indexes | Years | | | | |
|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2019 | 2020 |
| Capital investments, million hryvnias | 2502,81 | 2608,03 | 3505,92 | 4276,77 | 5595,32 |
| Final consumption, million hryvnias | 2378600,78 | 2976561,67 | 3550686,49 | 3966882,91 | 4208459,57 |
| Net final product, million hryvnias | 2381103,58 | 2979169,70 | 3554192,41 | 3971159,68 | 4214054,89 |

*Source: compiled by the author based on the source [8] and Table 1.*

3. Net final product: The value of net final product, which is represented as the difference between final consumption and capital investment, also increased during the period under review. From UAH 2,381,103.58 million in 2016 to UAH 4,214,054.89 million in 2020. This indicates the growth of net domestic production and income available for consumption and savings.

Gross domestic product Y(t) is modeled by the Cobb-Douglas production function:

$$Y(t)=AK(t)^{\alpha}L(t)^{1-\alpha}$$

A – is the technological coefficient, K(t) – is the cost of fixed assets, L(t) – is the number of the employed population, α and 1-α – are the coefficient of elasticity of

output for capital and labor resources, respectively. The dynamics of the variable L(t) is described by an exponential law:

$$L(t) = L_0 e^{nt},$$

Calculations are presented in Table 3.

**Table 3. Simulated GDP according to the Cobb-Douglas production function**

| Indexes | Years | | | | |
|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2019 | 2020 |
| Cost of fixed assets, million UAH | 8177408 | 7733905 | 9610000 | 9574186 | 10577278 |
| Number of employed population, persons | 162769000 | 16156400 | 16360900 | 16578300 | 15915300 |
| Technological coefficient | 0,01697 | 0,19232 | 0,22326 | 0,23945 | 0,27053 |
| Coefficient of elasticity of capital output | 0,049 | 0,055 | 0,048 | -0,004 | 0,048 |
| Coefficient of elasticity of output by labor resources | 0,95 | 0,95 | 0,95 | 1,00 | 0,95 |
| GDP, million hryvnias | 2385367 | 2983882 | 3 560 596 | 3978400,33 | 4222026 |

*Source: compiled by the author based on the source [8-11].*

According to the data in the table about the simulated GDP according to the Cobb-Douglas production function in Ukraine from 2016 to 2020, the following conclusions can be drawn:

1. Cost of fixed assets: Over the period from 2016 to 2020, the cost of fixed assets increased. Starting from 8177408 million UAH in 2016, it decreased in 2017 to 7733905 million UAH, but then increased again in 2018 and 2019, reaching a maximum value of 10577278 million UAH in 2020.

2. Number of the employed population: during the considered period, the number of the employed population changed, but generally showed a slight decline. From 162769000 people in 2016, it decreased to 15915300 people in 2020.

3. Technology ratio: The technology ratio, which indicates the level of technological development, increased from 0.01697 in 2016 to 0.27053 in 2020. This indicates the improvement of the technological potential of the Ukrainian economy.

4. The coefficient of elasticity of output by labor resources shows the dependence of the change in output on the change in labor resources. The value of this ratio remained stable at 0.95 during 2016-2018 but increased to 1.00 in 2019 and decreased again to 0.95 in 2020.

5. GDP: According to the Cobb-Douglas model, the simulated value of GDP in Ukraine also increased from 2016 to 2020. From UAH 2,385,367 million in 2016, GDP increased to UAH 4,222,026 million in 2020.

The change in the amount of capital K(t) considers investments and depreciation:

$$K(t+1) = K(t)+I(t)-D(t),$$

$D(t)= \delta_K K(t)$ – amount of depreciation, $\delta_K$ – fixed rate of depreciation. Calculations are presented in Table 4.

**Table 4. Dynamics of changes in the amount of capital during 2016 - 2020.**

| Indexes | Years | | | | |
|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2019 | 2020 |
| Amount of capital, million hryvnias | 8177408,00 | 7733905,00 | 9610000,00 | 9574186,00 | 10577278,00 |
| Investments, million UAH | -79716,00 | -160743,80 | -252198,40 | -260206,10 | 88267,04 |
| Amount of depreciation, million UAH | 4751074,05 | 4261381,66 | 5823660,00 | 5447711,83 | 6187707,63 |
| Change in the amount of capital, million hryvnias | 3346617,95 | 3311779,55 | 3534141,60 | 3866268,07 | 4477837,41 |

*Source: compiled by the author based on the source [10], [12], [13].*

Let's make some observations based on the data:

1. Expenditures on air pollution control and climate change issues increased during the period under review. From 2016 to 2020, they rose from 4,263.4192 million UAH to 7,971.1122 million UAH. This indicates a growing focus on environmental issues and climate change in Ukraine.

2. GDP also showed growth dynamics during the period from 2016 to 2020. It increased from 2,385,367 million UAH in 2016 to 4,222,026 million UAH in 2020. This reflects the overall economic development of the country.

3. Net final product (NFP) also exhibited growth during the period from 2016 to 2020. It increased from 2,381,103.58 million UAH in 2016 to 4,214,054.888 million UAH in 2020. This indicates that the production of goods and services was growing faster than expenditures on air pollution control and climate change issues.

4. Expenditures on air pollution control and climate change constitute a small percentage of GDP. For example, in 2016, this indicator accounted for 0.18% of GDP, and in 2020, it was 0.19%. This may indicate the need for more financial support and investments in climate protection measures to achieve more significant results.

5. The increase in expenditures on air pollution control and climate change issues may be related to the heightened awareness of environmental problems and the growing recognition of their importance for the country's sustainable development.

In the process of economic activity, carbon dioxide emissions occur that are proportional to the gross domestic product Y(t)

$$E(t)=\sigma(t)Y(t),$$

E(t) – emissions of carbon dioxide by stationary sources, σ(t) – is a technological parameter that reflects the trend character of the reduction of emissions per unit of GDP. It changes similarly to labor resources:

$$\sigma(t)=\sigma_e \sigma^{\sigma_1 t}$$

Calculations are presented in Table 5.

**Table 5. Emissions of carbon dioxide by stationary sources in 2016-2020.**

| Indexes | Years | | | | |
|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2019 | 2020 |
| GDP, thousand hryvnias | 2385367000 | 2983882000 | 3560596000 | 3978400333 | 4222026000 |
| Technological parameter (reduction of emissions per unit of GDP) | 0,0000013 | 0,0000009 | 0,0000007 | 0,0000006 | 0,0000005 |
| Emissions of carbon dioxide by stationary sources, thousand tons | 3078,1 | 2584,9 | 2508,3 | 2459,5 | 2238,6 |

*Source: compiled by the author based on the source [9], [14].*

Based on the table of carbon dioxide emissions from stationary sources in Ukraine from 2016 to 2020, the following conclusions can be made:

1. Technological Parameter: The value of the technological parameter, indicating the reduction of carbon dioxide emissions per unit of GDP, decreased during the period under review. It decreased from 0.0000013 in 2016 to 0.0000005 in 2020. This indicates an improvement in resource efficiency and a reduction in carbon emissions per unit of GDP.

2. Carbon Dioxide Emissions: The total volume of carbon dioxide emissions from stationary sources decreased during the period under review. They decreased from 3,078.1 thousand tons in 2016 to 2,238.6 thousand tons in 2020. This indicates positive developments towards reducing carbon dioxide emissions, although it should be noted that the decline in emissions was not linear, and there were fluctuations.

Emissions impact the average air temperature.

$$\overline{T}(t_0, t)=\phi_0 + \phi_1\overline{E}(t_0, t),$$

$\overline{T}$ ($t_0$,t) average air temperature for the period from $t_0$ to t, $\overline{E}(t_0,$ t) – average emissions for the period from $t_0$ to t, $\phi_0$ and $\phi_1$ – parameters.

The average temperature T(t) of period t is determined by the formula:

$$T(t)=(t-(t_0+1)\overline{T}((t_0, t)-(t-(t_0)\overline{T}((t_0, t-1).$$

Costs of atmospheric air protection and climate change problems depend on the value of GDP Y(t), temperature T(t) and technology:

$$TC(t)=\theta(t)Y(t)T(t),$$

θ(t) – is a technological parameter reflecting the reduction of costs per unit of GDP*degree Celsius above zero over time. It also varies exponentially.

$$\theta(t)=\theta_0 e^{\theta_1 t}.$$

Calculations are presented in Table 6.

**Table 6. Costs for atmospheric air protection and climate change problems in 2016-2020.**

| Indexes | Years | | | | |
|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2019 | 2020 |
| Technological parameter (reduction of costs per unit of GDP*degree Celsius above zero over time) | 0,00020 | 0,00016 | 0,00019 | 0,00019 | 0,00018 |
| GDP, million hryvnias | 2385367 | 2983882 | 3560596 | 3978400,33 | 4222026 |
| Average air temperature in Celsius | 8,8 | 9,8 | 9,6 | 9,4 | 10,7 |
| Costs for atmospheric air protection and climate change problems, million hryvnias | 4263,42 | 4712,30 | 6403,59 | 7240,66 | 7971,11 |

*Source: compiled by the author based on the source [8,9].*

According to the data from the table on expenses for air protection and climate change issues during 2016-2020, the following conclusions can be made:

1. Technological Parameter: The value of the technological parameter, indicating a reduction in expenses per unit of GDP for each degree Celsius above zero, decreased during the period under consideration. From 0.00020 in 2016, it decreased to 0.00018 in 2020. This reflects an improvement in resource efficiency and a decrease in expenses for air protection per unit of GDP with an increase in air temperature.

2. Gross Domestic Product (GDP): The total GDP increased during the period under consideration. From UAH 2,385,367 million in 2016, GDP grew to UAH 4,222,026 million in 2020. This indicates an increase in economic activity in the country.

3. Average Air Temperature: The average air temperature gradually increased during the period under consideration. From 8.8°C in 2016, it rose to 10.7°C in 2020. This reflects climate change and an increase in temperature in the country.

4. Expenses for Air Protection and Climate Change: Total expenses for air protection and climate change increased during the period under consideration. From UAH 4,263.42 million in 2016, they increased to UAH 7,971.11 million in 2020. This reflects increased investments and growing awareness of climate change issues.

Therefore, it can be observed that the Nordhaus Model is an important tool for Ukraine, as it allows for the consideration of ecological aspects in decision-making regarding the economy and development. The research demonstrates:

- The importance of analyzing how economic development affects the environment. Ukraine needs to preserve natural resources and reduce environmental risks, and this model helps find a balance between these goals.

- The ability to forecast the consequences of different economic and environmental scenarios, aiding the government and the business environment in understanding which decisions may have a negative impact on the environment and how to rectify them.

- An emphasis on sustainable development where economic growth and environmental preservation converges. This is particularly crucial for Ukraine as the country seeks ways to improve its economy while conserving natural resources for future generations.

- Its utilization in many countries and international organizations, allowing Ukraine to collaborate with other nations in addressing global environmental issues.

- The potential to attract investments into Ukraine by promoting green economy and sustainability.

- Its usefulness as a tool to attract investors who value sustainable development.

Integrating this model into policy and development strategies can contribute to creating a more sustainable and viable future for the country, including:

- Facilitating the transition to a green economy that promotes efficient resource utilization, emissions reduction, and job creation in clean technology sectors.

- Developing and implementing support programs for enterprises and economies that consume less energy and reduce greenhouse gas emissions.

- Conducting informational campaigns to increase public awareness of environmental issues and support environmental education initiatives.

- Investing in infrastructure that promotes energy conservation and the use of renewable energy sources.

- Involving businesses in the development and implementation of clean technologies and stimulating innovation in energy efficiency and environmental protection.

- Supporting the implementation and strengthening of environmental legislation and enforcement.

- Establishing a monitoring and reporting system for environmental indicators and the results of implemented measures.

These recommendations will not only improve the state of the environment but also create conditions for sustainable economic growth and an enhanced quality of life for Ukrainian citizens.

**Conclusions.** The research has shown that this model can be beneficial for analyzing the relationship between economic development and the state of the environment in the country. It affirmed that the state of the environment significantly influences the efficiency and sustainability of economic growth in Ukraine. Pollution, greenhouse gas emissions, and other environmental issues can lead to resource depletion and increased costs for environmental restoration. The importance of developing strategies that ensure a balanced development was highlighted. Efforts must be combined to facilitate economic growth and nature preservation. The use of models such as the Nordhaus Model is a valuable tool for forecasting and analyzing possible scenarios of economic development while considering environmental factors.

Research using the Nordhaus Model, considering environmental aspects, has significant potential for further studies. Research may include the development of alternative economic and environmental scenarios for Ukraine, enabling the examination of various balancing development options. Studies can evaluate the effectiveness of different policies and measures to improve economic growth and environmental conditions. It is essential to consider how global issues such as climate change or biodiversity loss affect regional economic development. Further research can provide specific recommendations for the Ukrainian government and the business environment to achieve sustainable development. All these research directions can contribute to expanding our understanding of the impact of ecology on the economy and promoting more sustainable and efficient development in Ukraine.

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