ECONOMIC AND ECOLOGICAL MODELING OF THE STRATEGY OF DEVELOPMENT OF ENTERPRISES FOR PROCESSING OF SECONDARY RAW MATERIALS

ЕКОНОМІКО-ЕКОЛОГІЧНЕ МОДЕЛЮВАННЯ СТРАТЕГІЇ РОЗВИТКУ ПІДПРИЄМСТВ З ПЕРЕРОБКИ ВТОРИННОЇ СИРОВИНИ

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This article examines the field of municipal solid waste management and recycling of secondary raw materials by the example of Kyiv. Every year, the amount of MSW is growing, but the share that is recycled is not increasing. In general, this area is characterized by its landfill orientation, low level of waste recycling and general waste accumulation. The paper recycling enterprise, its main economic indicators are considered. The model reflecting the relations between the region and the enterprise, taking into account the impact of the enterprise's production activity on the environment, is developed. Strategies for changing the management parameters for the enterprise and the region are proposed. These strategies include credit and price change strategies for secondary raw materials for the enterprise, as well as strategies for changing the ecological tax for the region. The analyzed situation is considered taking into account the scenarios of the economic situation in the country.
Key words: *municipal solid waste, environmental tax, hierarchical management, cybernetic system, economic and environmental models.*

В этой статье исследована сфера обращения с твердыми бытовыми отходами и переработки вторичного сырья на примере города Киева. С каждым годом количество твердых бытовых отходов растет, но доля, которая перерабатывается, при этом не увеличивается. В общем, данная сфера характеризуется ориентацией на полигонное захоронение, низким уровнем вовлечения отходов в качестве вторичного сырья и общим их накоплением. Рассмотрено предприятие по переработке макулатуры, его основные экономические показатели и разработана модель, отражающая отношения между регионом и предприятием с учетом влияния производственной деятельности предприятия на окружающую среду. Предложены стратегии изменения параметров управления для предприятия и региона, а именно, кредитные стратегии и стратегии изменения цены на вторичное сырье для предприятия, а также стратегии изменения экологического налога для региона. Исследуемая ситуация рассмотрена с учетом сценариев развития экономической ситуации в стране.
Ключевые слова: *твердые бытовые отходы, экологический налог, иерархическое управление, кибернетическая система, экономико-экологические модели.*

У сучасному світі все більше уваги приділяють проблемам екологічного характеру. У цій статті досліджено сферу поводження з твердими побутовими відходами та переробки вторинної сировини на прикладі міста Києва. З кожним роком кількість твердих побутових відходів зростає, але частка, що переробляється чи спалюється, при цьому не збільшується. Загалом дана сфера характеризується орієнтацією на полігонне захоронення, низьким рівнем залучення відходів у якості вторинної сировини та загальним їх накопиченням. Однією із основних проблем у даній сфері також виступає відсутність системи та культури сортування, а також слабка система оподаткування викидів від виробничої діяльності та відсутність системи заохочення підприємств до більш екологічного виробництва. Із збільшенням твердих побутових відходів виникає потреба у розвитку підприємств з переробки вторинної сировини та у максимізації уже наявних потужностей, що надасть змогу зменшити навантаження на навколишнє середовище регіону. Але відповідно зі зростанням виробничої діяльності регіональне управління має здійснювати контроль за викидами від цієї діяльності для того, щоб не погіршити екологічну ситуацію в регіоні. Розглянуто підприємство з переробки макулатури, його основні економічні показники, залежності між цінами та обсягами сировини, що збирається із різних джерел. Розроблено модель, що відображає відносини між регіоном та підприємством з урахуванням впливу виробничої діяльності підприємства на навколишнє середовище. Запропоновано стратегії зміни параметрів керування для підприємства та регіону, а саме, кредитні стратегії та стратегії зміни ціни на вторинну сировину для підприємства, і стратегії зміни екологічного податку для регіону. Розглянуто досліджувану ситуацію з урахуванням сценаріїв розвитку економічної ситуації в країні, за кожного із яких будуть змінюватись такі чинники як кількість населення, середня заробітна плата та індекс інфляції. Визначено прийнятну комбінацію стратегій для обох сценаріїв розвитку економіки, тобто таку комбінацію, що дозволить максимізувати корисність для регіону та інвестиції в основні фонди та власний прибуток підприємства, а також мінімізувати витрати підприємства на закупівлю вторинної сировини для переробки.
Ключові слова: *тверді побутові відходи, екологічний податок, ієрархічне управління, кібернетична система, економіко-екологічні моделі.*

Formulation of the problem. With the approval of the National Waste Management Strategy in Ukraine until 2030, recycling of secondary raw materials and responsible waste management have become extremely urgent problems of our country. The growth in need for recycling enterprises makes it necessary to develop these companies and maximize their existing capacities to reduce the burden on the environment. With the development of such enterprises and the increase in their production activities, the share of emissions into the atmosphere is also increasing. Therefore, regional administration should control emissions in order to ensure a better environmental situation.

Analysis of recent research and publications. The topic of economic and ecological models was explored by such scientists as S.A. Ashmanov [1], O.I. Ponomarenko, M.O. Perestiuk, V.M. Burym [2]. They considered mathematical modeling of the production process, taking into account the level of environmental pollution. Also, this topic was studied by Moiseev N.N. [3], whose work is devoted to the imposition of fines for environmental pollution by the regional administration of emissions from industrial activities. Among the recent studies, the work of Tadeiev Yu.P. [4] is also worth highlighting. He considers an ecological and economic model of optimal management of linear utility function, and the work of

Subbotina O.V., Tyutik O.V., Martyanov M.S. [5], who considered an integrated approach to the management of secondary resources on the regional level.

Formulation of the goals of the article. The purpose of this article is to model a cybernetic hierarchical system where enterprises and a region are considered. With the help of ecological tax, a region can influence the implementation of a more ecological approach in production by enterprises. It forms hypotheses about possible behavior of these enterprises and the way they choose their own economic strategy of development, taking into account their influence on the environment.

Outline of the main research material. Consider the situation with the management of waste based on the example of the city of Kyiv. Municipal solid waste (MSW) is generated through the consumption of different types of products. The amount of generated waste depends on the number of consumers and the money they spend. The process cannot occur without one of these factors. Manufacturing packaging technology or the technology of products that later become MSW changes with time. In other words, the amount of waste can increase with the same number of people and their income. Therefore, the amount of MSW generated will also be affected by scientific and technological progress. Then, the econometric dependence between the generated amount of MSW, average salary and population can be defined by the production function, which takes into account scientific and technological progress:

$$\Upsilon(t) = DK(t)^{\alpha} L(t)^{\beta} e^{rt} \qquad (1)$$

where Υ – amount of MSW generated in the city, tons; K – average salary in the city, UAH; L – population of the city, people.

In order to obtain the result, the value of average salary was reduced to 2011 base year prices. Then the function of MSW formation in the city of Kyiv will look as follows:

$$\Upsilon(t) = K(t)^{-0,50} L(t)^{8,71} e^{0,044t-58,29}. \qquad (2)$$

The amount of waste paper generated in Kyiv is a certain share of the total amount of waste generated. It is difficult to estimate how the share of waste paper in the morphological composition of MSW will change with time. It is almost impossible to determine what types of packaging and materials will appear in the future, or how the use of paper products will change. Therefore, for simplification, we will assume that this share is a constant value (for Kyiv it is 13%). The amount of waste paper formed, respectively, is determined by the following formula:

$$\Upsilon_m(t) = q_m \Upsilon(t), \quad 0 \le q_m \le 1, \qquad (3)$$

where Υ_m – amount of waste paper, tons; q_m – the share of waste paper in the total composition of solid waste, %.

Let us consider private joint-stock company “Kyiv Cardboard and Paper Mill” (KCPM), which specializes in cardboard and paper production. The waste paper is the primary type of raw materials that it uses. The company produces a certain amount of products and gets a gross profit by subtracting production costs and taxes on added value as well as excise duty.

The gross profit of the enterprise can be defined using a multiplicative production function, as the production process cannot be carried out without the simultaneous use of fixed assets of the enterprise and its human resources.

KCPM’s production capacity for recycling of waste paper is not fully utilized, although the number of generated waste paper tends to grow. Recycling of waste paper is less expensive in comparison with cellulose processing. It saves electricity and water. Also the price for the equivalent amount of wood is higher than the price of waste paper. Therefore, it is more profitable for KCPM to use waste paper in its production. It accounts for 90% of the raw materials used in this enterprise. Therefore, the production function also includes the resources of secondary raw materials.

In 2018, KCPM received a 7-year loan from the European Bank for Reconstruction and Development in the amount of 10 million euros. This loan is used by the company to modernize its production technology, which allows it to reduce CO_2 emissions to 11000 tons/year and save about 2 million EUR/year on electricity. It will also allow the company to purchase new converter and packaging lines, upgrade equipment, which will contribute to the expansion of their range of products, improve their quality and reduce production costs.

The production function of the gross profit will take into account the factor of disbursed investments,

Table 1

Statistical data for calculation of regression dependence of the amount of MSW in the city of Kyiv

Year	Amount of MSW, thousand tons	Average salary, UAH	Population, thousands of people	Inflation index
2011	278.7	4016.41667	2785.1	1.046
2012	835.8	4610.58333	2814.3	0.998
2013	530.5	5023.83333	2845	1.005
2014	1058.9	5401.25	2868.7	1.249
2015	1128.6	6545.18182	2888	1.433
2016	1236.8	8585.58333	2906.6	1.124
2017	548.4	11134.25	2925.8	1.137

which will influence the scientific and technological advancement of the enterprise. With the help of attracted external funds in the form of credit, KCPM invests in modernization of its technologies.

The inflation index should also be included in this function. It will indicate the purchasing power of the population and will characterize the final actual value of gross profit based on the economic situation in the country. Then the multiplicative function that models the gross profit of an enterprise will look as follows:

$$Q_m(t) = A(I_m)F(\Phi_m,\Lambda_m,M_m) = \\ = BI_m(t)^{\beta}\Phi_m(t)^{\varphi}\Lambda_m(t)^{\theta}M_m(t)^{\mu}\, h^{t}(t), \quad (4)$$

where Q_m – gross profit, UAH; $A(I_m)$ – a progress multiplier, which determines the efficiency of investments in technological progress; I_m – disbursed investments in the modernization of technological progress of the enterprise, UAH; F – multiplicative production function, Φ_m – fixed assets, UAH; Λ_m – labor resources, people; M_m – volumes of waste paper processed by the enterprise, tons; h – inflation index.

The value of gross profit, disbursed investments and funds was reduced to the 2011 base year prices. Therefore, the gross profit function of KCPM looks as follows:

$$Q_m(t) = I_m^{0,25}(t)\Phi_m^{-0,28}(t)\Lambda_m^{-0,83}(t)\mathrm{M}_m^{0,52}(t)h^{2,182}(t)e^{20,78}. \quad (5)$$

The labor resources of the enterprise are calculated taking into account the annual growth rate of employees in the enterprise and change according to the following formula:

$$\Lambda_m(t+1) = \Lambda_m(t)(n_m(t+1)+1), \quad t = 0,1,\ldots,T-1\,. \quad (6)$$

where $n_m(t+1)$ – annual growth rate of labor resources, %. For simplification, we will consider that this indicator does not depend on time and it will be set at the level of -0.0231.

Gross profit of the enterprise can be divided into several parts. One part is its own profit, which may be used for consumption. The enterprise should choose which part of the gross profit to allocate to its own profit:

$$s_m(t) = \alpha Q_m(t)\,,\ 0 \le \alpha(t) \le 1\,, \quad (7)$$

where α – share of own profit; s_m – own profit of the enterprise, UAH.

The second part of the gross profit of the enterprise is used for repaying credit obligations. The company can choose which credit is more advantageous for it: at what interest rate and in what amount. Since it is not specified exactly which scheme the company will pay its loan obligations by, it has been decided to take the scheme of debt amortization in equal installments in the form of simple annuity-intermidiate with a term of T years. Then the cost of paying off the loan obligations in each period would be calculated as follows:

$$V_m(t) = IA\frac{IR}{1-(1+IR)^{-T}} \quad (8)$$

where V_m – payments on credit obligations, UAH; IA – initial loan amount, UAH; IR – interest rate,%; T – the term, for which the loan was taken, in years.

It is impossible to estimate exactly under which scheme a company is developing the investments received and modernizing its production. Therefore, for the simplification it has been decided that they will be used by the enterprise in equal parts and will accumulative over time.

$$\Delta I_m = \frac{IA}{T}\,, \quad (9)$$

$$I_m(t+1) = I_m(t) + \Delta I_m\,,\ t = 0,1,\ldots,T-1\,. \quad (10)$$

The third part of the gross profit can be invested in fixed assets. It will equate to gross profit minus part of the enterprise's own profit and part that goes to repay its credit obligations. A change in fixed assets will be defined as an investment in fixed assets, reduced by depreciation costs.

$$Y_m(t) = (1-\alpha)Q_m(t) - V_m(t)\,, \quad (11)$$

$$\Delta\Phi_m(t) = (1-\alpha)\,Q_m(t) - V_m(t) - \psi\Phi_m(t), \quad (12)$$

where Y_m – investments in fixed assets from own funds, UAH; $\Delta\Phi_m$ – change in fixed assets of the enterprise, UAH; ψ – depreciation rate of fixed assets.

The change in emissions from production will be expressed as the amount of emissions that depends on the gross profit of the enterprise, minus the part of emissions that will be reduced as a result of the investments made in the modernization:

$$\Delta\pi_m(t) = \varepsilon Q_m(t) - r_m I_m(t)\,,\ r_m > 0\,, \quad (13)$$

where $\Delta\pi_m$ – volume of emissions from production of the enterprise, tons; ε – emissions from 1 UAH of gross profit, tons/UAH (for the KCPM, this indicator is equal to $0{,}00001299692$ tons/UAH); r_m^{-1} – the amount of invested money, which allows to reduce

Table 2

Statistical data for calculating the regression function of gross profit

Year	Gross profit, thousands of UAH	Investments, thousands of UAH	Fixed assets, thousands of UAH	Labor resources, workers	The amount of waste paper, tons
2011	435403	277727	516114	2 032	62 231.00
2012	506685	241682	578940	2 135	160 291.02
2013	412340	199318	641340	2 360	155 994.45
2014	478177	147565	1309270	2 517	169 219.41
2015	1033032	152957	1364081	2 093	173 807.34
2016	1110066	230370	1303531	1 672	152 766.92
2017	1171665	308144	1366332	1 851	173 974.96

CO_2 emitted into the atmosphere by a ton, tons/UAH (for KCPM this indicator is 19486.7 tons/UAH).

During the manufacturing process, the main type of emissions produced by the KCPM is CO_2. To regulate the emissions of this enterprise, the regional administration may set a certain environmental tax rate for the amount of CO_2, that the enterprise has generated. The administration will have an opportunity to collect certain payments from the enterprises in accordance with these rates and changes in the amount of pollution in a given period. The region can form strategies on how the environmental tax rate will change in each period of time. The amount of environmental tax payments to enterprises will look as follows:

$$\omega_m(t) = \Delta\pi_m(t)z(t) = z(t)\left(\varepsilon Q_m(t) - r_m I_m(t)\right), \quad (14)$$

where ω_m – environmental tax for pollution, which must be paid by the enterprise, UAH; z – environmental tax rate per 1 ton of CO_2, UAH/ton.

Gross profit in general will look as follows:

$$Q_m(t) = Y_m(t) + V_m(t) + (s_m(t) - \omega_m(t)) + \omega_m(t). \quad (15)$$

Consider the target functions and limitations for the region and the enterprise. Firstly, let us describe the situation from the enterprise side. The first target function reflects the enterprise's intention to minimize the cost of raw materials for the entire period, so the target function is important for the enterprise and is not translated into constraints:

$$\sum_{t=1}^{T} P(t) \to min. \quad (16)$$

The expenses of the enterprise for raw materials will be calculated as the sum of volumes of waste paper that are gathered at the secondary raw material collection points, in sorting tanks and are imported, multiplied by corresponding prices.

$$P(t) = m_1\left(c_{m1}(t)\right)c_{m1}(t) + m_2\left(c_{m2}(t)\right)c_{m2}(t) + \\ + m_3\left(c_{m3}(t)\right)\left(1 + j(t)\right)c_{m3}(t), \quad (17)$$

where P – total cost of waste paper, UAH; m_1 – volume of recycled paper collected at secondary raw material collection points, kg; m_2 – the amount of waste paper that is collected from sorting tanks, kg; m_3 – volume of imported waste paper, kg; c_{m1} – price per 1 kg of waste paper gathered from secondary raw material collection points, UAH; c_{m2} – costs per 1 kg of waste paper collected from sorting tanks, UAH; c_{m3} – price per 1 kg of imported waste paper, UAH; j – rate of import duty per ton of imported raw materials,%. As of today, imported waste paper is not subjected to import duty, which means the import duty rate per ton of imported raw materials will be equal to zero.

The quantity of raw materials, gathered from the collection points and sorted into tanks should aim at the maximum value for the whole period. The enterprise is interested in getting as much waste paper as possible and using the maximum capacity of its production facilities.

$$\sum_{t=1}^{T}(m_1\left(c_{m1}(t)\right) + m_2\left(c_{m2}(t)\right)) \to max. \quad (18)$$

The company is not directly interested in maximizing only the volume of waste paper, which is gathered from collection points and in sorting tanks, because it can cover the shortage from imported raw materials. Therefore, this target function can be converted into a limitation. The amount of waste paper that is gathered at collection points for secondary raw materials and sorted in tanks should not be less than the amount of waste paper collected by such methods for the previous period. The amount of waste paper, which has been formed in 2011-2017, is 5617720 tons, and part of it that has been sorted in tanks and gathered at collection points is 26%, that is 1460602 tons.

$$\sum_{t=1}^{T}(m_1\left(c_{m1}(t)\right) + m_2\left(c_{m2}(t)\right)) \geq 1460602. \quad (19)$$

An enterprise may aim to maximize the funds invested in fixed assets and the funds it allocates to its own profit. Any business is interested in maximizing its own profit. Therefore, we will leave this criterion as another target function of the enterprise:

$$J_m = \sum_{t=1}^{T}\left(Y_m(t) + s_m(t)\right) \to max, \quad (20)$$

$$Y_m(t) + s_m(t) = Q_m(t) - V_m(t), \quad (21)$$

$$J_m = \sum_{t=1}^{T}\left(Q_m(t) - V_m(t)\right) \to max. \quad (22)$$

Fixed assets of the enterprise in the last year of the analyzed period should be maximized.

$$\Phi_m(T) \to max. \quad (23)$$

In this instance, the company is not very interested in expanding its own capacities, as its existing capacities are not yet fully utilized. In addition, it is already improving its manufacturing process. Therefore, this criterion can be converted into a limitation. Consideration of the analyzed situation begins in 2018. Therefore, at the threshold value, which should not be lower than the value of fixed assets in the last year, we should take the value in 2017. After reducing the 2017th value to the 2011th base year prices, the fixed assets of the company will total 647 370 659 UAH.

$$\Phi_m(T) \geq 647370659. \quad (24)$$

The volumes of collected waste paper must be greater than the company's capacity in each period of time in order for the company to operate at full capacity:

$$\sum_{i=1}^{3} m_i\left(c_{mi}(t)\right) \geq M\left(\Phi_m(t)\right). \quad (25)$$

As investments are made to improve the technological process, manufacturing capacity can also change. In this case, the capacity of the enterprise will depend on the fixed assets of the enterprise. This process can be described as an econometric dependence:

$$M\left(\Phi_m(t)\right) = G\Phi_m^{\varsigma}(t). \quad (26)$$

Table 3

Statistical data for calculation of regression dependence of waste paper processing capacity

Year	Waste paper processing production capacity, tons.	Fixed assets, thousands of UAH
2012	211650	553 479.92
2016	359556	694 199.74
2018	373500	647 370.66

Table 4

Statistical data for calculation of the dependence between volumes and prices of waste paper at recycling collection points

Year	Price of waste paper, UAH/kg	Amount of waste paper delivered, tons	Inflation index
2011	0.75	3323.1354	1.046
2012	0.8	7308.0036	0.998
2013	1.2	4926.951	1.005
2014	1.1	8621.8038	1.249
2015	1.3	8731.8612	1.433
2016	2.7	12510.7656	1.124
2017	2.4	7432.8528	1.137

where M – production capacity for waste paper processing, tons.

The value of the funds was reduced to base year prices of 2011. Therefore, the function of KCPM waste paper recycling capacity looks like:

$$M\left(\Phi_m(t)\right) = \Phi_m{}^{2,555}(t)e^{-21,49}. \quad (27)$$

Volumes of waste paper gathered at collection points and sorted into tanks should be less than the amount of waste paper produced in a given period:

$$\sum_{i=1}^{2} m_i\left(c_{mi}(t)\right) \le \mathrm{Y}_m(t). \quad (28)$$

Volumes that are sorted in tanks should not exceed the amount that can be collected in the maximum set number of containers in a given period:

$$m_2\left(c_{m2}(t)\right) \le b_m(t), \quad (29)$$

$$\Delta b_m = \frac{b_{max}}{T}, \quad (30)$$

$$b_m(t+1) = b_m(t) + \Delta b_m,\ t = 0,1,\ldots,T-1. \quad (31)$$

where b_m – the maximum amount of waste paper that can be collected into sorting containers available in the given period of time, kg; b_{max} – the maximum amount of waste paper that can be collected in sorting containers, if the optimal number of containers is installed, kg.

In August 2019, a pilot project on waste sorting has launched in Kyiv and 2.5 thousand containers have been installed. The maximum number of sorting bins needed in the city is calculated on the basis of research on the necessary number of bins for the city of Vyshhorod. In this study, 200 bins have been installed for a population of 35 000 people covering 80% of the city. Using the population of Kyiv in 2018, the required number of containers has been calculated. Based on the amount of waste paper that fits into one container, the maximum amount of waste paper that can be placed in this number of tanks can be calculated. According to the calculations, we get:

$$b_{max} = 5780651 \text{ tons}. \quad (32)$$

The amount of waste paper that is gathered at secondary raw materials collection points will depend on the price of waste paper. Statistical information on raw material prices has been reduced to the 2011 base year prices. On its basis, the dependence has been deduced:

$$m_1\left(c_{m1}(t)\right) = 8537,4c_{m1} - 1390,6. \quad (33)$$

The price and volumes of waste paper from sorting tanks will also be interconnected. Assuming that the waste is taken out once a week, we will calculate the cost per 1 kg of raw material, collected from the sorting tanks. To do this, we calculate the respective container costs per 1 kg of raw material based on such indicators as the useful life of the container, the price of the container and the container capacity for the particular type of raw material.

Also, the costs of the raw materials collected from the sorting tanks include the salaries of the drivers who transport these materials and the cost of the vehicles, which are used. Having determined the capacity of one vehicle per 10 tons, the number of vehicles and drivers required to transport the raw materials is calculated according to the number of containers, and the cost of the vehicles is calculated according to the amounts collected.

The calculated dependence of volumes of waste paper (in 2019 prices) that are collected in sorting tanks prices will have the following form:

$$m_2\left(c_{m2}(t)\right) = 7873,3c_{m2}{}^{-1,364}. \quad (34)$$

The volumes of imported raw materials will also depend on the price because the higher the price of imported raw materials, the less profitable for domestic enterprises will be to purchase such raw materi-

als, and therefore its volumes will be lower. Then, if the price for imported raw materials is lower, then the amounts of this raw material will be greater. Statistical information on raw material prices was reduced to the 2011 base year prices. On its basis, the dependence was deduced:

$$m_3\left(c_{m3}(t)\right) = -10000000c_{m3} + 400000000\,. \quad (35)$$

Table 5

Statistical data for calculation of dependence between the amounts of imported waste paper and its prices

Year	Amount of waste paper, kg	Price of waste paper, UAH/kg
2014	329400000	5.81777778
2015	336900000	4.84378747
2016	271800000	4.70045622
2017	346400000	5.42378753
2018	392300000	5.24074433

The region will be able to raise money by collecting an environmental tax. At the same time, it will be necessary to figure out how to reduce concentrations of CO_2, as carbon dioxide will accumulate in the atmosphere and affect the environment and climate change in the region. On the one hand, the region benefits from the environmental tax it collects from businesses for their emissions into the atmosphere. On the other hand, the region suffers losses in terms of neutralizing the environmental impact of these emissions. Then the function of the region's utility will look as follows:

$$u_m(t) = \left(\omega_m(t) - \vartheta\Delta\pi_m(t)\right), \quad (36)$$

where u – utility function; ϑ – costs for neutralization of the impact of 1 ton of emissions of CO_2 on the environment, UAH/ton (for the considered situation this indicator is 15.02 UAH/ton).

The region is interested in successfully controlling the situation regarding emissions from the production activities of enterprises and getting the maximum benefit from the established system of penalties. Accordingly, this target function is of priority importance for the region and remains a target function:

$$W_m = \sum_{t=1}^{T}\left(u_m(t)\right)e^{-\rho t} \to max\,. \quad (37)$$

where W_m – optimality criterion; ρ – discount rate.

The discount rate in this instance is assumed to be equal to the average bank discount rate (in this instance the indicator is 0.1725).

The amount of waste paper left in landfills, which releases CO_2, will be calculated as the total amount of waste paper generated in the region minus the waste paper used in production at the mill:

$$\Delta M_m(t) = M_{max}(t) - M_m(t), \quad (38)$$

where ΔM_m – amount of waste paper remaining at landfills, tons; M_{max} – the total amount of waste paper that was created during this period, tons.

This has a positive impact on the atmosphere, as the amount of CO_2, which waste paper emits during decomposition in landfills, decreases. Thus, the level of pollution will be measured as the amount of pollution produced by the company, with the exception of a part, which will be assimilated by the environment, and part of the emissions that could have been generated if the waste paper had remained in the landfill:

$$\Delta x_m(t) = (\Delta\pi_m(t) + \sigma_m\Delta M_m(t))(1-\gamma_m),\ \gamma_m > 0\,, \quad (39)$$

where $\Delta x_m(t)$ – the level of pollution, tons; γ_m – rate, at which production waste is assimilated into the environment, tons/year (in this case, the indicator is equal to 0.01 tons/year); σ_m – amount CO_2, which is released into the atmosphere from 1 ton of waste paper per year, tons/year (in this situation, this indicator is equal to 0.04 tons/year).

The regional administration aims to ensure that the level of pollution in the region is not too high, while not restricting the activities of enterprises too much. The level of environmental pollution in each year should strive to minimum.

$$\Delta x_m(t) \to min,\quad t = 0,1,\ldots,T-1\,. \quad (40)$$

This target function is less of a priority for the region and may become a limitation. The level of pollution at each point in time should not be higher than the value of the pollution level of the emission in the previous year before the period under study (2017). In 2017, the level of carbon dioxide emissions in Kyiv was 5400000 tons:

$$\Delta x_m(t) \le 5\,400\,000,\quad t = 0,1,\ldots,T-1. \quad (41)$$

Let us consider 2 scenarios of the country's developments, which will affect the situation being considered. The first scenario is characterized by financial crisis. Because of the crisis, there will be changes in the population of the city of Kyiv. Analyzing a similar situation from another period of time (the crisis of 2008), we can see that the balance between the arrivals and departures from the city tends to decrease, but, in general, it will be positive and consequently the number of population in the city will also increase.

The second scenario is characterized by a stable economic situation. Indicators such as average wages and population in Kyiv would follow a similar trend, as in the previous review period from 2011 to 2017. Then, by building trend dependencies for both indicators, we can determine what they will be like in the period under study.

Also, based on the change of the inflation index during the previous crisis, it is possible to calculate the inflation index for the crisis situation and with the help of trend dependencies we can determine its value for a stable economy.

Trend dependencies of population, average wage and inflation index for a stable economy will look as follows:

$$K(t) = 226,98t^2 - 719,41t + 4807,5\,, \quad (42)$$

Table 6

Changes in the population size, average wage and inflation index from 2018 to 2024 in the context of the crisis

Year	Population, thousands of people	Change in population compared to last year,%	Average salary, UAH	Change in average wages compared to last year,%	Inflation index,%	Change in inflation index compared to last year,%
2018	2934.50		13547.583		109.8	
2019	2958.03	-3.9	18132.89	33.846	114.8	5.00
2020	2980.22	-4.2	18661.56	2.916	119.7	4.89
2021	2993.41	-29.6	20283.57	8.692	111.5	8.6918
2022	3002.10	-24.9	23661.14	16.651	108.7	16.6517
2023	3010.59	-1.8	27161.44	14.7935	104.5	14.7935
2024	3025.87	58.5	29595.94	8.9631	99.94	8.9631

Table 7

Strategies of the enterprise regarding the rate and amount of credit

№ of strategy	Term for which the loan is taken, years	Initial loan amount, EUR	Interest rate,%
Strategy 1	7	10 000 000	6.85
Strategy 2	7	5 000 000	7.41

$$L(t) = -1,5536t^2 + 35,5t + 2750,9\,, \qquad (43)$$

$$h(t) = 14,98\ln(t) + 134,46\,. \qquad (44)$$

The enterprise can choose which credit is more advantageous for it. According to the available offers on rates and loan amounts, the enterprise can form the following strategies for itself.

The tax rate that a region sets in a given period is a factor that it can manage. The region can form strategies for how the rate will change in each period. The first strategy was based on a proposal by the International Monetary Fund. The IMF proposes carbon taxes as an effective tool to reduce emissions of CO_2. The strategy is to gradually increase the tax for developed countries on CO_2 to 75 dollars per ton until 2030, and for developing countries to 25 dollars per ton or 682 UAH/ton. The second strategy was based on existing plans to change the ecological tax in Ukraine. In 2019 the tax rate on CO_2 increased almost 25 times from 0.41 UAH/ton to 10 UAH/ton. The future plan is to increase the tax rate by 5 UAH/ton every year.

Consider 2 strategies of how the price of waste paper may change at secondary raw material collection points. According to the first strategy, the price may increase in order to encourage the public to turn in the waste paper. Thus strategies for the studied period the price will increase from 2.5 UAH/kg to 4.43 UAH/kg. According to the second strategy, the price may on the contrary decrease in order to compete with imported raw materials, which are cheaper. The price will decrease from 2.5 UAH/kg to 1.33 UAH/kg.

For each combination of strategies, the value of three target functions for the enterprise and the region was calculated, taking into account their limitations, in two economic scenarios. By converting these criteria into an absolute value and comparing them in pairs, the Pareto multitude was created. Based on the principle of guaranteed result, an acceptable strategy combination was chosen for both crisis and stable economic situations. The strategy is a combination of the second credit strategy, the strategy of changing the environmental tax proposed by the IMF, and the strategy of reducing the price of waste paper at the receiving points for recycled materials. Table 8 illustrates changes in gross profit, funds and Table 9 illustrates changes in the amount of emissions and prices of secondary raw materials from year to year

Table 8

Changes in gross profit and funds of the enterprise taking into account the inflation index for the selected strategy for both scenarios

Year	Gross profit, UAH		Fixed assets, UAH	
	Crisis situation	Stable situation	Crisis situation	Stable situation
2018	857 575 717	857 575 717	1 540 489 191	1 540 489 191
2019	1 475 982 743	1 304 990 547	1 433 021 842	1 433 021 842
2020	2 253 972 120	1 686 380 308	1 767 488 794	1 581 439 722
2021	2 612 108 945	2 011 273 967	2 521 896 843	1 843 767 683
2022	3 116 461 432	2 289 814 041	3 029 234 467	2 137 147 037
2023	3 463 131 067	2 521 899 133	3 534 632 438	2 415 363 939
2024	3 626 626 339	2 701 638 328	3 880 847 812	2 651 377 435

Table 9

Changes in waste paper prices at receiving points, emissions from production, and the inflation index for the selected strategy for both scenarios

Year	Price of waste paper in collection points, UAH/kg		Amount of pollution, ton		Inflation index	
	Crisis situation	Stable situation	Crisis situation	Stable situation	Crisis situation	Stable situation
2018	2.50	2.50	15030	15030	1.098	1.098
2019	2.47	2.47	20083	18447	1.148	1.085
2020	2.55	2.41	23380	19445	1.197	1.068
2021	2.75	2.32	21432	19841	1.115	1.050
2022	2.76	2.19	21419	19947	1.087	1.033
2023	2.70	2.04	20621	19909	1.045	1.015
2024	2.54	1.86	19464	19790	0.999	0.998

for both economic scenarios. The changes are brought to actual values in accordance with inflation indices.

Conclusions from the study. During the study, it has been found that among the existing problems in the processing of secondary raw materials utilization of existing processing facilities and low efficiency of the emissions tax system are of insufficient capacity. A proposed model reflects the relationship between processing enterprises and the region, and suggests strategies for parameters that region and enterprise manage. The calculations have shown that a combination of strategies with a second credit strategy, proposed environmental tax change strategy of the IMF and a strategy to reduce the price of waste paper at recycling points, was favorable for both economic situations. In both economic scenarios, gross profit and fund performance increases. This indicates the economic development of enterprises. In the table, there can be seen that in actual prices, the gross profit of fixed assets of enterprises grow faster in a crisis situation, compared to a stable one because of the inflation index. But in prices consolidated to the base year, these indicators grow faster when the economic situation is stable. Emissions do not exceed the limit value, which indicates a normal environmental situation in the region. The review of the model built for enterprises processing other types of secondary raw materials with due account of their specific features remains a promising direction. It is also recommended to introduce an import duty rate on waste paper at an average rate of 2.2% to limit the volume of imported waste paper. Thus, the model can be recommended for use by the management of the regions, where the enterprises, processing secondary raw materials, are developing.

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