Implementation of the Concept of Circular Economy in Ukraine

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Abstract: The concept of circular economy of Ukraine's processing industry on the basis of combination of modern practical experience and economic and mathematical methods and models is developed in the work. The concept includes many stages aimed at stabilizing Ukraine's processing industry in the conditions of transformational changes. Each stage requires appropriate information support, statistical and economic methods of information processing. The decision-making process is based on a scenario approach to modeling, using a modern economic and mathematical apparatus. The relationship between the stages is realized through a system of direct links and feedback, which determine the sequence of management actions. A method of generalizing the index of ecological and economic development has been developed to compare the pace of sectoral development and the amount of damage caused to the environment.

Sustainable economic growth in the long run must be ensured by intensive development factors. That is why it is proposed to compare the sectoral index of environmental load with the corresponding index of economic development. In turn, the latter should indicate not only the physical volume of total production at comparable prices, but also reflect the qualitative nature of changes that have occurred during sectoral development, and were associated with a reduction in the share of intermediate consumption. The generalized index of sectoral ecological and economic development thus received will show efficiency of introduction of principles of circular economy in the operation of processing industry companies during the reporting period, and also due to the proposed actions. The economic substantiation of a complex of measures on recycling of the processing sector of Ukraine aimed at maintaining sustainable development is carried out.

During 2016-2018, the processing industry created favorable conditions for moderate economic growth, which was accompanied by a reduction in pollution of all kinds. A positive result was achieved due to metallurgical production and mechanical engineering. Since the development and implementation of closed-loop technologies in production activities requires significant investment resources, the recommendations in this case are to maintain existing trends by intensifying environmental measures and further implementing them.

It was found that the implementation of measures to minimize the generation of waste within the processing industry only will not be able to radically solve the problem of its generation and accumulation. The solution can only be a comprehensive modernization of the entire economy, in particular, the extractive industry;

In the structure of waste use, the largest share, exceeding 70%, was occupied by waste disposal in specially designated areas, and only about 30% accounted for utilization. This situation has developed primarily due to the extraction of iron ore. Areas of possible use of this type of waste are: further processing and extraction of residual minerals at ferrous metallurgy enterprises as building materials of the construction industry. However, given the use of outdated technologies, further processing is not economically feasible. Therefore, in the long run, Ukraine's industry should reorient from the extraction and primary processing of resources to the production of high-tech products with a high share of added value.

Keywords: circular economy, sustainable development, closed ecological and economic cycle, economic and mathematical methods and models

JEL: O1, O2, O3, O4

Introduction

Based on the world experience of the introduction of the circular economy as a form of organization of social production, which involves the reuse of waste from economic activities and households [1-5], as well as products whose life cycle is nearing completion as resources, we have proposed the concept of development of the ecological and economic cycle of Ukraine's. processing industry. Sustainable socio-economic development based on a linear model of the economy has obvious advantages in improving the welfare of the population. But in the long run, it has significant shortcomings that threaten the energy, environmental and economic security of the state. The negative consequences of a linear economy are manifested in the form of: uncontrolled use of natural resources, which over time leads to their depletion, deficit and rising prices; environmental pollution due to atmospheric emissions, including carbon dioxide, use of fresh water, deforestation, as well as fertilizer and pesticide application; accumulation of waste, landfills, which now occupy about 7% of the total territory of Ukraine; etc.

In contrast, the circular economy, or closed-loop economy, is considered by modern scientists as part of the fourth industrial revolution. It is based on the principle of recycling of any product, resulting in minimization of waste from economic activities, a significant reduction in consumption of natural resources, as well as the transition to renewable resources.

The urgency of implementing the principles of the circular economy in the activities of enterprises in the processing industry of Ukraine is primarily due to significant consumption of natural resources and damage to the environment as a result of air emissions and large amounts of waste.

Research on this topic is just beginning to gain momentum, but contributions to the problems and prospects of the circular economy have been made by such foreign and Ukrainian scientists as Chen Demin, W. Stachel, N. Boken and E. Olivetti, P. J. Matthews, K. Fletcher, O. Ulanova, S. Miroshnichenko and others. Members of the Club of Rome - E. Weizsäcker, A. Wijkman, D. Meadows and A. Peccei – all of whom made a significant contribution to the development of ecologically oriented activities. Among Ukrainian researchers, attention was paid to this issue in the works of: N. Gakhovych, L. Deineko, O. Dronova, I. Zvarych, A. Zygun, O. Maleya, V. Mishchenko, L. Sergienko-Berdyukova, I. Tymoshenko and others.

Theoretical premises

The developed concept consists of many stages aimed at stabilizing the processing industry of Ukraine in the conditions of transformational changes. Each stage requires appropriate information support and statistical and economic methods of information processing. The decision-making process is based on a scenario approach to modeling, using a modern economic and mathematical apparatus. "The relationship between the stages is realized through a system of direct links and feedback, which determine the sequence of management actions" [6]. Thus, the concept implements the principles of modern approaches to management in the economy, namely:

- the process approach is based on the need for continuous management, whose sequence is determined by the stages of the concept and the set of direct links between them;
- a system-based approach considers the processing industry as an open system that interacts with other sectors of the economy and consumers of final products. Resources are fed to the input of this system; at the output we get the total products and the corresponding level of environmental pollution. One part of the generated waste is fed through feedback to the input of the system as resources for reuse, and the other - accumulates in the places of their disposal;

- a situational approach is based on the need for constant analysis of the current situation to develop and make adequate decisions, and is implemented in the form of feedback between the stages of the concept.

Detailing of the stages of the concept was performed according to the functional purpose. We propose to consider them in more detail.

Stage 1. Collection of input statistics. Input data is collected in statistics areas of key macroeconomic indicators, such as: inflation rate, gross domestic product, total output, etc.;

- volumes of environmental pollution by atmospheric emissions, use of water resources and waste generation by types of economic activity;
- waste management statistics by region;
- "costs-output" statistical tables;
- volumes of current expenses and capital investments for environmental protection.

The obtained input data and the results of their initial processing are transferred to the next stage of the concept.

Stage 2. Defining a set of indicators to assess the sectoral level of environmental load.

As mentioned above, the amount of environmental pollution in statistical practice is measured by such indicators as: use of fertilizers and pesticides, forest resources, air pollution, collection and use of water resources, waste generation and management, etc. The first two groups of indicators are directly related to agriculture, forestry and fisheries, so they were not included in the concept of development of the ecological and economic cycle of the processing industry of Ukraine.

Regarding the conceptual apparatus, the environmental load will be understood as the amount of damage caused to the environment from all types of pollution during a certain period, in relation to the region.

Stage 3. Analysis of trends in environmental and economic development in the processing industry.

Any management should be based on the results of a preliminary analysis of the current situation and current trends in the dynamics of the studied indicators [7-10]. That is why this stage of the concept is mandatory and is part of the feedback loop.

The methodological support of this stage of the analysis is the model of the index of sectoral ecological and economic development, created by the author. It is based on the premise that the current dynamics of environmental load can not indicate the effectiveness of changes in the circular economy, as the reduction of environmental pollution may be associated with an even greater reduction in total production and vice versa. That is why it is proposed to compare the sectoral index of environmental load with the corresponding index of economic development. In turn, the latter should indicate not only the physical volume of total production at comparable prices, but also reflect the qualitative nature of changes that have occurred during sectoral development, and were associated with a reduction in the share of intermediate consumption.

The generalized index of sectoral ecological and economic development thus received will show efficiency of introduction of principles of circular economy in the activity of enterprises of the processing industry during the reporting period, and also due to the suggested actions.

Stage 4. Effective waste management in the industry. To analyze the effectiveness of waste management, taking into account the criteria of the circular economy, the paper proposes to use a system of indicators that allow a comprehensive assessment of interrelated activities for:

1) Prevention of waste generation. The priority of this measure is due to the fact that the absolute minimization of waste eliminates the need for all subsequent stages of their management.
2) Waste management structure management. It is known from [11] that “the current European waste management standards are based on the following hierarchy of priorities: - preparation of waste for reuse; - processing and utilization; - other types of utilization, such as energy recovery by incineration; - waste disposal by confining it to specially designated areas. "In contrast, domestic statistical practice keeps records of waste use in such areas of assessment as" [12]: - utilization; - incineration; - waste disposal in specially designated places; - placement of waste in landfills. Therefore, considering the concept of ecological and economic development of the country, or the relevant industry on the basis of a circular economy, this hierarchy of priorities should form its basis. It should also be borne in mind that open statistics contain information on waste management by region, not by type of economic activity.

3) Minimization of volumes and concentration of accumulated waste. Large amounts of accumulated waste today pose a threat to the environmental situation of some regions in Ukraine. That is why this direction of assessment is an important element of effective management.

Stage 5. Development of scenarios for environmental management of industrial products. The results of the previous two stages are the basis for the development of scenarios for the management of environment-friendly production in the processing industry. By environmental friendliness, in this case, we mean prevention of the total damage to the environment caused as a result of all stages of production, to final consumption. It is obvious that the volume of environmental pollution only by the processing industry can not be a criterion for the environmental friendliness of its products, as this is only one of the intermediate or final stages of its production. Due to the close cross-sectoral links, the final product goes through many stages of processing by various industries, which have a negative impact on the environment. Thus, if the products obtained are non-environmentally friendly, the problem may lie not only in the processing industry, but also in other suppliers of raw materials, in particular, the mining industry. In this case, processing companies can change existing counterparties to those whose social and environmental responsibility of the business is at a higher level, which is also due to the expansion of foreign trade relations. This will increase the environmental friendliness of production by changing the structure of intersectoral relations only.

"The methodological basis of these calculations is the Leontief inter-industry balance model " [13-14], which uses aggregate statistical "Costs-output" tables as input data. With its help we are able to assess the current state and develop scenarios for managing the environmental friendliness of production in the following main areas:

- calculation of the amount of total damage to the environment that was caused during the production in a particular sector of the economy, taking into account all stages of value-added production;
- analysis of the anthropogenic impact of all industries involved in the production of final products of the processing industry;
- scenario analysis of the effect of the spread of the forecast final demand on the environmental friendliness of production, etc.

Stage 6. Economic assessment of the consequences of sectoral development in the transition to a circular economy.

"All the above measures to implement the principles of the circular economy need their economic evaluation" [15]. In some cases, they are new resource-intensive technologies with a long payback period, which require the use of financial mathematics and evaluation of the effectiveness of investment projects. In other cases, this problem can be solved on the basis of multi-criteria evaluation of the results of scenario modeling, which was carried out at the previous stage.

Methodology

Next, we consider in more detail the methodological support of the stages of the proposed concept. The problem of quantitative measurement of the index of ecological and economic development in the processing industry is to be assessed in this study on the basis of geometric means, as the analysis of trends in its components is based on relative indicators of dynamics.

The sectoral index of economic development includes two factors: the sectoral average annual GDP growth rate and their relation to the growth rate of total output. Both indicators should be maximized, which indicates quantitative and qualitative positive changes.

(1) $$IEP = \sqrt{T_{GDP} \times T_{GDP/CB}}$$

where *IEP* is a sectoral index of economic development; T_{GDP} is an average annual growth rate of sectoral GDP;

$T_{ВВП/СВ}$ – the ratio of the growth rate of sectoral GDP to the growth rate of total output.

Formula (1) applies if both factors have the same weight. If experts give greater preference to one of the factors, then the formula will look like a geometric weighted average.

(2) $$\bar{x} = \sqrt[\sum a_i]{\prod_{i=1}^{n} \left(x_i^{a_i}\right)}$$

where $\bar{x}$ is a geometric weighted average x_i – the average annual growth rate of the i factor;

a_i – weighting factor of the i factor; n is the number of multiplier factors.

Considering that $\sum_{i=1}^{n} a_i = 1$ and taking into account the entered symbols, formula (1) takes the form:

(3) $$IEP = T_{GDP}^{a_1} \times T_{GDP/CB}^{a_2}$$

We get the greatest positive effect when the industry not only increases value added, but also reduces the share of intermediate consumption, which indicates an increase in the efficiency of its activities.

The sectoral index of environmental load is formed on the basis of the growth rate of environmental pollution in all areas of assessment.

(4) $$IEH = \sqrt[n]{\prod_{i=1}^{n} T_{E_i}} \quad \text{or} \quad IEH = \prod_{i=1}^{n} \left(T_{E_i}^{a_i} \right)$$

where *IEH* is the industry index of environmental load;

T_{E_i} is the average annual growth rate of pollution in the j direction of assessment, per 1 thousand km2 area;

n – number of types of pollution.

By analogy, the first interpretation of formula (4) assumes the same weight for each type of pollution; the second - different weights, in accordance with the system of preferences of the expert.

The direction of optimization of each is minimization. It means that the average annual volume of the *i* type of pollution in absolute terms tended to decrease and vice versa. Accordingly, the IES performance indicator should also be minimized.

Then, the generalized index of sectoral ecological and economic development, within the transition of the processing industry to a closed-cycle economy, will be calculated by the formula:

(5) $$I_{\Gamma} = \frac{IEP}{IEH}$$

where I_{Γ} is the generalizing index of branch ecological and economic development

Given the direction of optimization of the numerator and denominator, this generalized IG index should be maximized.

Thus, the proposed model of the sectoral index of ecological and economic development, in contrast to the existing ones, allows to conduct a quantitative analysis of the results concerning the formation of a closed ecological and economic cycle of Ukraine's processing industry and develop recommendations for its activation.

The quality of waste management by region is determined by the structure of its use. Preference is given to recycling, whose share should be maximized relative to other uses. The next priority is the incineration of waste to generate electricity or heat. It is undesirable, according to the criteria of circular economy, to remove waste to specially designated areas. It is also practiced in Ukraine to dispose of waste in landfills, the share of which should be reduced to zero. Thus, effective waste management involves the presence of structural changes that lead to a redistribution of their share in favor of priority uses and vice versa.

Below, we consider the model for estimating structural changes in waste dynamics. To do this, we introduce conventional symbols. Let us presume that:

- volumes of waste generation by regions are given by vector $УB[n]$, where *n* is the number of regions of Ukraine; $УB_i$ - volumes of waste generation in the *i* region as a result of economic activity and household waste production.
- volumes of waste use by region are indicated by matrix, where *m* is the number of areas of waste use for which statistical accounting is conducted (utilization, incineration, disposal in specially designated places, placement in landfills), *m = 4*; BB_{ij} - the amount of waste used in the *j* direction in the *i* region. Then, $УB_i = \sum_{j=1}^{m} BB_{ij}$ is the volume of waste generation in the *i* region is equal to the total volume of its use in all regions.
- volumes of accumulated waste by region are given by vector $HB[n]$, where HBi are volumes of accumulated waste in the *i* region in specially designated places and in natural landfills.

The last of the considered indicators is connected with the previous discrete dynamic equation, which has the following form:

(5) $$HB_i(t) = HB_i(t-1) + BB_{i3}(t) + BB_{i4}(t)$$

where $HB_i(t)$ and $HB_i(t-1)$ are the volumes of accumulated waste in the *i* region, in the reporting and previous periods, respectively;

$BB_{i3}(t)$, and $BB_{i4}(t)$ are, accordingly, the volumes of waste in the *i* region, disposed during the reporting period in specially designated places and placed in landfills.

To assess the structural changes in the use of waste, based on the introduced conventional symbols, the appropriate shares are calculated:

(6) $$BB_{SB,ij} = \frac{BB_{ij}}{YB_i} \quad \text{for all} \quad i = 1\ldots n,\ j = 1\ldots m,$$

where $BB_{SB,ij}$ is the share of the *j* direction of waste use in the total amount of its generation in the *i* region.

It should be noted that $\sum_{j=1}^{m} BB_{SB,ij} = 1$ for all *i* = 1…n.

In statistical practice, indicators of absolute growth and particle growth rate are used to analyze structural shifts. Estimation of intensity of structural shifts occurs on the basis of linear or quadratic coefficients of variation.

Regarding the use of waste, the effective implementation of the circular economy principles should ensure the redistribution of specific weight:

- $BB_{SB,i4}$ in favor of $BB_{SB,i3}$, $BB_{SB,i2}$ and $BB_{SB,i1}$;
- $BB_{SB,i3}$ in favor of $BB_{SB,i2}$ and $BB_{SB,i1}$;
- $BB_{SB,i2}$ in favor of $BB_{SB,i1}$.

The ultimate goal of the desired changes is the disposal of all generated waste by region, ie $BB_{SB,i1} = 1$ for each i region = 1… n.

The disadvantage of traditional indicators of the intensity of structural changes used in general statistics is only a quantitative assessment of the relative magnitude, rather than the direction of changes in waste management. However, as we have seen, it is the direction of structural changes that determines the effectiveness of measures to form a closed ecological and economic cycle. That is why it was suggested in the paper to use additive-multiplicative convolution, which, taking into account the entered notations, has the following form:

(7) $$C_{BB,i} = \sum_{j=1}^{m} \left(\alpha_j \times BB_{SB,ij}\right), \quad CC_{BB,i} = \sum_{j=1}^{m} \left(\alpha_j \times \Delta BB_{SB,ij}\right), \quad \text{for all } i = 1\ldots n,$$

where $C_{BB,i}$ and $CC_{BB,i}$ are, accordingly, summarized indicators of the structure and structural changes of waste use in the *i* region.

α_j – weighting factor that determines the priority of the *j* direction of waste use;

$\Delta BB_{SB,ij}$ – change in the share of the *j* direction of waste use in the *i* region in the reporting period, compared to the baseline.

"When conducting multifactor analysis, in economic and mathematical analysis, a common practice is the use of additive-multiplicative convolutions to determine the generalized indicators" [16-18]. "In this case, the input factors are normalized for the segment" [0; 1] to ensure the comparability of their values.

The weights of the factors are positive, and their sum should be equal to 1. The values of the weights are different methods of expert evaluation and coordination of opinions. "As a result of such a convolution, the generalized indicator also takes values from 0 to 1 and should be maximized" [19].

Regarding the indicator of the structure of waste use, formula (7), it significantly differs from the above methodology:

- as input factors of this convolution indicators of specific gravity are used, which can take values from 0 to 1, but their sum will always be equal to 1;
- to ensure the condition of $C_{BB,i}$ belonging to the segment [0; 1], the weights must also be within $0 \le \alpha_j \le 1$, but at least one value must be equal to $\alpha_j = 1$

Thus, the standard decision-making methods for determining the system of α_j preferences cannot be applied in this case, as the requirements for weights differ from traditional ones.

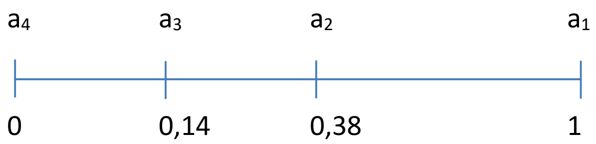
The undisputed priority of the circular economy is the utilization of waste in full, therefore, $\alpha_1 = 1$. Then $C_{BB,i} = 1$ at $BB_{SB,i1} = 1$. This means that 100% utilization of waste will have the maximum value of the consolidated indicator of the structure of their use, which follows from the economic content of the problem.

Another extreme case is the disposal of waste in landfills. As a phenomenon, it should not exist, therefore $\alpha_4 = 0$. Then, $C_{BB,i} = 0$ at $BB_{SB,i4} = 1$.

"Accordingly, the determination of quantitative estimates of α_2 and α_3 and for the incineration of waste and its disposal in specially designated areas requires scientific justification. To address this issue, the paper proposes to use the proportion of "Golden Ratio", which is part of the concept of harmonious management" [20-22].

"Golden Ratio" provides for a division of the segment "[0; 1] into two intervals, in which the smaller interval is correlated with the larger in the same way as the larger interval with the whole segment. In practice, the approximate value of the larger interval is 0.62, the smaller - 0.38. In our case, the weights of the consolidated indicator of the structure of waste use will take values, as shown in Figure 1.

Figure 1. Weighting factors of the consolidated indicator of the structure of waste use in the "Golden Ratio" proportion



Source: own elaboration

"The value of the α_2 coefficient divides the segment [0; 1] in the "Golden Ratio" proportion. Given the overriding priority of waste disposal before incineration, $\alpha_2 = 0{,}38$. Similarly, coefficient α_3 divides the segment" [0; 0.38], giving the main advantage of waste incineration before disposal in specially designated areas. So, $\alpha_3 = 0{,}14$.

Thus, according to the developed concept of ecological and economic cycle development, we have built a model for assessing structural changes in waste use, which allows us to assess the direction of changes in the implementation of the principles of the circular economy.

The cluster analysis of waste management by regions is based on indicators of their use structure. This makes it possible to carry out a scientifically sound classification of Ukraine's regions, determine the centers of development of the circular economy and the causes of lags. The results of calculations according to the formula (7) are used as input data.

"The practical implementation of the method of cluster analysis involves a certain iterative process, which results in clarification of the affiliation of each of the objects of assessment to a particular group" [23-25].

1. Initial clustering. The purpose of this stage is to determine the number and primary composition of each group, which includes regions with a similar structure of waste use. The criterion for combining regions is the Euclidean distance, which is calculated between each pair of objects of study by the formula:

(8) $$D_{iz} = \sqrt{\sum_{j=1}^{m} \left(BB_{SB,ij} - BB_{SB,zj}\right)^2}$$

where D_{iz} – Euclidean distance between the i and z regions in the structure of waste use.

"Lesser values indicate greater similarity between the *i* and *z* regions. The initial clustering begins with the search for two administrative units, the distance between which is the shortest and equal to D_{min}. These two objects form a cluster, which should include all the others, the distance to which is less than $(10 - K) \times D_{\min}$ where K belongs to the segment "[1; 10) and is determined so that the quality of the clustering was the highest. The K parameter affects the number of groups and their composition. The quality criterion, in this case, is the silhouette measure, which is calculated after the iterative process is completed.

The initial clustering should determine the affiliation of each region to a set of those with a similar waste management structure.

2. Re-clustering. Based on the classification of regions carried out at the previous stage, the calculation of the centers of gravity for each group is performed using the arithmetic mean. The affiliation of each region to a particular cluster is determined by finding the minimum distance between them and the calculated centers of gravity. As a result, the previous composition of each group may change. This step must be repeated iteratively as long as the numerical composition of the clusters continues to change.

"As noted above, when conducting a scientifically sound grouping of objects by a certain set of features, a topical issue is the quantitative assessment of the quality of such clustering". To do this, according to existing practice, we will calculate the silhouette measure.

(9) $$CM_i = \frac{D_{i2} - D_{i1}}{\max(D_{i1};\ D_{i2})}, \quad CM = \frac{\sum_{i=1}^{n} CM_i}{n},$$

where CM_i is an individual indicator of the silhouette measure for the *i* object;-

D_{i1}, D_{i2} –are the distance from the *i* object to its center and the nearest cluster, respectively;

CM – generalized indicator of the silhouette measure.

The CM value can take values from -1 to 1 and should be maximized. An acceptable level of classification is achieved if $CM \geq 0{,}2$; $CM \geq 0{,}5$ is high. Otherwise, the clustering procedure must be repeated with a different value of the K parameter.

"Next, consider a model for assessing the environmental friendliness of products based on the intersectoral balance". To do this, enter the symbols:– volumes of environmental pollution are indicated by the matrix $E[n \times m]$, where *n* is an aggregate number of branches of Ukraine's economy; m is the number of types of pollution; E_{ij} is the absolute amount of pollution of the *j* type and the *i* industry during the reporting period. Then, $E_j = \sum_{i=1}^{n} E_{ij}$ is the total amount of pollution of the j-th type in the economy as a whole;

- is the vector of total output $X[n]$, where X_i is the volume of total output of the i industry. Then, $Z_{ij} = \frac{E_{ij}}{X_i}$ is the average level of the j type of pollution in the i industry, per 1 million UAH. total output.
- is the vector of final demand $F[n]$, where F_i is the value of the final demand for products of the i industry. Then, $\frac{E_{ij}}{F_i}$ is the average level of the j type of pollution by the i branch, per 1 million UAH of final demand;
- is the intermediate consumption matrix $X[n \times n]$, where Xij is the volume of intermediate consumption by the j branch of production of the i region.

Due to the high inertia of macroeconomic processes, the structure of intersectoral relations, based on the introduced symbols, is determined using a matrix of direct costs $A[n \times n]$:

(10) $$a_{ij} = \frac{X_{ij}}{X_j}$$

where a_{ij} is the direct cost ratio;

X_j is the total output of the *j* industry.

Then, the basic equation of intersectoral balance in matrix form takes the following form:

(11) $$X = AX + F$$

The solution of equation (11) assumes the finding of the aggregate output X, which satisfies the scenario final demand F and the corresponding intermediate consumption A and is written in the form (12):

(12) $X = (I - A)^{-1} F$, $B = (I - A)^{-1}$ $\rightarrow X = BF$, $\rightarrow \Delta X = B \Delta F$,

where *I* is a single matrix;

B is a full cost matrix;

ΔF , ΔX - the change in final demand and aggregate output, respectively

Therefore, the environmental indicator, or the change in the amount of pollution of the *j* type with increasing final demand for products of the *i* industry, which leads to a corresponding increase in aggregate output, will be calculated with the formula (12):

(13) $$EK_{ij} = \sum_{i=1}^{n} \left(B \Delta F_i \times Z_{ij} \right)$$

where EK_{ij} is the environmental friendliness of the production unit of the i industry by the j type of pollution.

Thus, the change in the final demand for the products of only one industry, according to the distribution effect, which is determined by the structure of intersectoral relations, leads to a corresponding change in aggregate output in all industries. This, in turn, immediately affects the amount of damage to the environment for all types of pollution. Thus, we considered the economic and mathematical support of the concept of development of the ecological and economic cycle of Ukraine’s processing industry. In further research it is necessary to focus on the economic substantiation of the basic directions of introduction of bases of circular economy in activity of the enterprises of Ukraine’s processing sector.

Results

According to the developed concept, the substantiation of the main directions of development of the ecological and economic cycle of Ukraine’s processing industry should begin with the collection of input statistical data and the definition of many indicators to assess the level of environmental load. A detailed description of these concept blocks has been discussed above. Further, to analyze the existing environmental and economic trends in the industry, a model based on the interrelated *IEP*, *IEH* and I_r indices is used. The corresponding components of the indices of economic development and environmental load are calculated in Table 1.

Table 1. Calculation results of the generalized index components of ecological and economic development according to the 2016-2018 data

Industries	*IEP components*		*IEH components*				
	T_{GDP}	$T_{GDP/CB}$	T_{E1}	T_{E2}	T_{E3}	T_{E4}	T_{E5}
1	2	3	4	5	6	7	8
1. Agriculture, forestry and fisheries	0,959	0,984	0,98	1,16	0,83	1,22	1,13
2. Mining and quarrying	1,057	1,076	0,98	1,14	1,13	0,83	0,85
3. Processing industry, including:	1,013	1,006	0,95	0,89	0,96	0,98	0,99
3.1. Food production	1,000	1,027	1,05	1,08	1,05	0,98	0,97
3.2. Production of coke and petroleum products	0,940	0,875	1,00	1,05	–	–	–
3.3. Metallurgical production	1,016	0,987	0,94	0,84	0,99	0,98	0,99
3.4. Other processing industry	1,035	1,018	1,00	0,97	0,75	1,01	1,01
4. Electricity, gas, steam and air supply	1,039	1,001	0,84	0,93	0,92	0,97	0,97
5. Water supply, sewerage, waste management	0,959	0,952	1,07	0,77	0,93	1,01	1,01
6. Construction	1,113	0,989	0,99	0,68	1,12	1,03	1,09
7. Other activities	1,044	0,994	0,88	0,88	0,87	1,09	0,76
Total	1,029	1,004	0,90	0,92	1,09	1,07	1,01

Source: own elaboration

According to the results of calculations, favorable conditions have developed in the processing industry in recent years, according to which moderate economic growth due to quantitative and qualitative factors was accompanied by a reduction in pollution of all kinds.

Regarding the pace of economic development, we can see from column (1) that in 2016-2018, the processing industry lagged behind the average economic level. However, in terms of production efficiency, column (2), the share of value added in total output grew faster at processing plants. Thus, the annual growth rate of sectoral GDP was + 1.28% and exceeded the corresponding growth rate of total output, which was + 0.72%. This reduced the dependence on intermediate consumption, which is positive and necessarily accompanies the process of transition to a circular economy.

Regarding the ecological load, it is possible to state the reduction of environmental pollution per 1 thousand km2 in all areas of anthropogenic impact, columns (4) - (8). The most significant among other sources is the reduction of atmospheric emissions, in particular, carbon dioxide, which was -11.47% annually. This favorably distinguished the processing industry from the economy as a whole, as waste generation, water intake and use tended to increase here.

The next stage of the concept involves the development of recommendations for waste management. The relative effectiveness of measures to prevent waste generation can be assessed according to column (6), table. 1. In Ukraine, the annual volume of waste generation in 2016-2018 increased by 9.4%, from 295,870.1 thousand tons to 352,333.9 thousand tons. The main polluters were the mining and processing industries. Regarding processing enterprises, the volume of waste generation decreased from 34,093 thousand tons to 31,523.2 thousand tons, or -3.8% annually.

Another feature of waste generation is their territorial irregularity. The largest polluter is the Dnipropetrovsk region, where in 2018 this figure was 243,598.8 thousand tons, or 69.1% of all waste in Ukraine. The consequence of this is another problem. The total amount of waste accumulated in disposal sites in the Dnipropetrovsk region at the end of the reporting period amounted to 10712,436.6 thousand tons, or 82.6% of Ukraine's total. This is the result of activities in the extraction industry, which generates up to 87% of waste. In particular, the share of metal ore mining in their industry volume is 93.7%. In the short term, waste generation can be significantly reduced only by reorienting to foreign suppliers of raw materials and energy resources. In the course of their activities in 2018, households generated 5,543.5 thousand tons of waste, or only 1.60% of its volume in Ukraine. The next stage of the concept provided for the management of the structure of waste use on the basis of a certain hierarchy of priorities in the "Golden Ratio" proportion" [20-26].

Summary indicators of structure and structural shifts, which were calculated for Ukraine as a whole according to formulas (7), take the values: $C_{BB,2016}$ = 0.390; $C_{BB,2018}$ = 0.397; $C3_{BB}$ = +0.007. Thus, the pace of positive dynamics that has emerged in recent years will not solve the problem of insufficient waste disposal, even in the long run. In the regional aspect, the structure of waste use is quite uneven (Table 2):

Table 2. Analysis of structural changes in waste use by region according to the 2016-2018 data

Regions	Structure of waste use, %				$C_{BB,2018}$	CC_{BB}
	Utiliza-tion	Incinera-tion	Disposal in specially designated places	Placement at landfills		
1	2	3	4	5	6	7
Vinnytsia	27,03%	3,28%	69,69%	0,00%	0,383	0,080
Volyn	21,35%	3,82%	74,83%	0,00%	0,336	0,030
Dnipropetrovs’k	34,92%	0,01%	65,07%	0,00%	0,443	0,021
Donets’k	27,67%	0,02%	72,31%	0,00%	0,381	0,077
Zhytomyr	10,06%	9,07%	80,87%	0,00%	0,252	-0,030
Zakarpattia	0,21%	3,22%	96,56%	0,00%	0,154	-0,003
Zaporizhzhia	62,82%	0,99%	36,19%	0,00%	0,684	0,046
Ivano-Frankivs’k	28,07%	6,21%	65,72%	0,00%	0,399	-0,060
Kyiv	2,42%	1,54%	96,03%	0,00%	0,169	-0,008
Kirovohrad	4,89%	0,07%	95,04%	0,00%	0,186	-0,034
Luhans’k	8,16%	5,40%	86,37%	0,07%	0,227	-0,117
Lviv	16,57%	2,15%	81,28%	0,00%	0,291	-0,007
Mykolayiv	2,54%	1,19%	96,22%	0,05%	0,169	-0,007
Odessa	1,26%	7,49%	91,24%	0,00%	0,173	0,010
Poltava	13,98%	0,23%	85,79%	0,00%	0,265	-0,452
Rivne	4,79%	12,72%	82,47%	0,02%	0,215	-0,032
Sumy	23,23%	2,48%	74,29%	0,00%	0,349	-0,049
Ternopil	14,57%	0,27%	85,16%	0,00%	0,270	0,041
Kharkiv	17,50%	4,25%	78,25%	0,00%	0,304	-0,032
Kherson	8,51%	6,09%	85,40%	0,00%	0,232	0,020
Khmelnytsky	55,62%	1,12%	43,24%	0,01%	0,623	0,180
Cherkassy	53,03%	1,12%	45,84%	0,00%	0,601	-0,034
Chernivtsi	29,58%	2,69%	67,73%	0,00%	0,404	-0,019
Chernihiv	15,31%	1,95%	82,74%	0,00%	0,280	0,007
City of Kyiv	0,22%	21,78%	78,00%	0,00%	0,198	0,016

Source: own elaboration

- leaders in waste disposal in 2018, where their share exceeded 50%, were Zaporizhia (62.8%), Khmelnytsky (55.6%) and Cherkasy (53.05) regions. At the same time, the largest lags in this indicator took place in Zakarpattia (0.2%), Odesa (1.3%), Kyiv (2.4%), Mykolaiv (2.5%) and Kyiv (0) , 2%);
- despite the low average share of waste incineration in Ukraine, in certain areas it has found wide practical use: Kyiv (21.8%), Rivne (12.7%), Zhytomyr (9.1%), Odessa (7, 5%), Ivano-Frankivsk (6.2%), and Luhans'k (5.4%) regions;
- the worst situation of waste disposal was observed in Zakarpattia (96.6%), Mykolayiv (96.2%), Kyiv (96.0%), Kirovohrad (95.0%) and Odessa (91.2%) regions.

The values of the regional indicators of the structure are given in column (6) of Table 1, and structural changes that took place during 2016-2018, in column (7). As we can see, the most effective waste management, in terms of reuse, currently operates in Zaporizhia (C_{BB} = 0.684), Khmelnytsky (0.623) and Cherkasy (0.601) regions. Conversely, the most problematic regions are: Zakarpattia (0.154), Kyiv (0.169), Mykolaiv (0.169), Odessa (0.173), Kirovohrad (0.186) regions and Kyiv (0.198). There was also a pattern of structural changes: the leading regions in waste reuse improved their positions, and those with the largest lag worsened their standing.

Methods of cluster analysis allow to conduct a scientifically sound classification of regions of Ukraine according to the structure of waste use. Columns (2) - (5) of table 2 were used as input data. In substantiating the value of the *K* parameter, we proceeded from the following assumptions:

- Firstly, the high level of quality of the classification of regions must be confirmed by the appropriate value of the silhouette measure. That is, the center of each cluster must well characterize the objects that are part of it. Also, the distance of each object to the center of its cluster should be much smaller than to the centers of other clusters;
- Secondly, excessive diversification of management measures through the formation of a significant number of clusters is undesirable. Therefore, it is optimal that a small number of groups be created, and their components combined with common conditions of development.

Given the above, as a result of the clustering performed at the value of the K parameter = 2.5, we formed 4 groups of regions with a common waste use structure. The first cluster includes Zaporizhia, Khmelnytsky, and Cherkasy regions with the highest level of waste utilization (Table 3).

Table 3 Classification of areas with respect to the structure of waste use, cluster I

Regions	Structure of waste use, %				$C_{BB,2018}$	CC_{BB}
	Utilization	Incineration	Disposal	Landfills		
Zaporizhzhia	62,82%	0,99%	36,19%	0,00%	0,684	0,046
Khmelnytsky	55,62%	1,12%	43,24%	0,01%	0,623	0,180
Cherkassy	53,03%	1,12%	45,84%	0,00%	0,601	-0,034
Cluster center	57,16%	1,08%	41,76%	0,00%	0,636	–

Source: [State Statistics Committee of Ukraine]

The generalized indicator of the structure of waste use, calculated by the center of this cluster, is the maximum relative to other regions of Ukraine and is equal to 0.636. The indicator of structural changes allows us to assess the trends that took place in waste use during 2016-2018. As we can see, in Zaporizhia and Khmelnytsky regions the situation of reuse improved, while it worsened in Cherkasy region.

The next two clusters were characterized by a significant reduction in the share of recycled waste in favor of disposal in specially designated areas. They included the vast majority of Ukraine's regions. Thus, the composition of the second cluster is given (Table 4).

Table 4. Classification of areas with respect to the structure of waste use, cluster II

Regions	Structure of waste use, %				$C_{BB,2018}$	CC_{BB}
	Utilization	Incineration	Disposal	Landfills		
Vinnytsia	27,03%	3,28%	69,69%	0,00%	0,383	0,080
Volyn	21,35%	3,82%	74,83%	0,00%	0,336	0,030
Dnipropetrovs'k	34,92%	0,01%	65,07%	0,00%	0,443	0,021
Donets'k	27,67%	0,02%	72,31%	0,00%	0,381	0,077
Ivano-Frankivs'k	28,07%	6,21%	65,72%	0,00%	0,399	-0,060
Sumy	23,23%	2,48%	74,29%	0,00%	0,349	-0,049
Chernivtsi	29,58%	2,69%	67,73%	0,00%	0,404	-0,019
Cluster center	26,96%	3,79%	69,24%	0,00%	0,384	–

Source: [State Statistics Committee of Ukraine]

The center of the cluster indicates that the average share of recycled waste decreased over 2 times relative to the areas of the first group. Regarding the trends of structural changes, the relationship between C_{BB} and CC_{BB} is not identified. Thus, the problem of waste reuse in these areas is very common: taking into account incineration, this figure is around 30%.

The most numerous is the third cluster, the composition of which is presented (Table 5).

Table 5. Classification of areas with respect to the structure of waste use, cluster III

Regions	Structure of waste use, %				$C_{BB,2018}$	CC_{BB}
	Utilization	Incineration	Disposal	Landfills		
Zhytomyr	10,06%	9,07%	80,87%	0,00%	0,252	-0,030
Luhans'k	8,16%	5,40%	86,37%	0,07%	0,227	-0,117
Lviv	16,57%	2,15%	81,28%	0,00%	0,291	-0,007
Poltava	13,98%	0,23%	85,79%	0,00%	0,265	-0,452
Rivne	4,79%	12,72%	82,47%	0,02%	0,215	-0,032
Ternopil	14,57%	0,27%	85,16%	0,00%	0,270	0,041
Kharkiv	17,50%	4,25%	78,25%	0,00%	0,304	-0,032

Kherson	8,51%	6,09%	85,40%	0,00%	0,232	0,020
Chernihiv	15,31%	1,95%	82,74%	0,00%	0,280	0,007
City of Kyiv	0,22%	21,78%	78,00%	0,00%	0,198	0,016
Cluster center	8,01%	9,94%	82,05%	0,00%	0,236	–

Source: [State Statistics Committee of Ukraine]

In addition to a significant reduction in the share of recycling, the areas of this cluster have the largest share of waste incineration among the regions in order to obtain energy. However, waste disposal is dominant and exceeds 80%. As a result, the C_{BB} indicator for the center of the cluster is 0.236, which is extremely low.

The analysis of structural shifts testifies to multidirectional dynamics in the directions of waste management. Poltava region deserves special attention. During 2016-2018, the share of recycling decreased from 66.7% to 14.0%. This is the largest reduction in all of Ukraine. The causes of this phenomenon are an increase in waste generation by 3.7 times, from 5,421.3 to 1,9825.7 thousand tons. At the same time, the volume of utilization decreased by 23.3%, from 3,615.2 to 2,771.7 thousand tons. The last, fourth, cluster unites regions where waste utilization is practically absent (Table 6).

Table 6. Classification of areas with respect to the structure of waste use, cluster IV

Regions	Structure of waste use,, %				$C_{BB,2018}$	CC_{BB}
	Utilization	Incineration	Disposal	Landfills		
Zakarpattia	0,21%	3,22%	96,56%	0,00%	0,154	-0,003
Kyiv	2,42%	1,54%	96,03%	0,00%	0,169	-0,008
Kirovohrad	4,89%	0,07%	95,04%	0,00%	0,186	-0,034
Mykolayiv	2,54%	1,19%	96,22%	0,05%	0,169	-0,007
Odessa	1,26%	7,49%	91,24%	0,00%	0,173	0,010
Cluster center	2,90%	2,92%	94,17%	0,02%	0,176	–

Source: [State Statistics Committee of Ukraine]

As a result, the indicator of the structure of waste use, calculated by the center of the cluster, took the lowest value among those discussed above, which is negative.

As a result of the grouping, the indicator of the silhouette measure will be equal to $(CM = 0{,}64) \geq 0{,}50$, which corresponds to a high level. Therefore, when developing measures for the implementation of the principles and provisions of the circular economy in the activities of processing enterprises, it is possible to take into account the regional division by the use of waste. Based on the results of the analysis, it can be concluded that in Ukraine today the restrictions on the circular economy regarding the complete reuse of waste are not met. Moreover, the existing structure of waste use and the corresponding structural changes indicate that companies are not interested in implementing any changes to improve the environment. This is a systemic problem in almost the entire territory of Ukraine, except for three regions.

"The main reason for this unsatisfactory situation is the operation of the mining industry, in particular, the extraction of metal ores, due to which more than 80% of the volume of all industrial and household waste is generated annually in Ukraine" [27]. They include: residues of unextracted components, which may be up to 15-20% of the initial volume of extraction; oxidized quartzite; silicate and carbonate; natural stone and clay rocks; gravel and sand.

Areas of possible use of these types of waste are: further processing and extraction of residual minerals at ferrous metallurgy enterprises, as building materials for the construction industry. However, given the use of outdated technologies, further processing is not economically viable. On average in Ukraine, the total amount of accumulated waste per 1 km^2 in 2018 was 22,498.9 tons, i.e 306,896 kg per person. However, these averages are not representative, as they poorly characterize the study population: almost all regions, except for a few, have much lower concentrations.

Table 7. Calculation of the integrated indicator of accumulated waste according to the 2018 data

Regions	Accumulated waste		Normalized accumulated amount of waste		Integral indicator, %
	Tons per 1 km^2	Кg per 1 person	Tons per 1 km^2	Кg per 1 person	
1	2	3	4	5	6
Vinnytsia	1201,8	20305	0,9964	0,9939	99,03%
Volyn	408,2	7931	0,9988	0,9976	99,64%
Dnipropetrovs’k	335571,1	3328076	0,0000	0,0000	0,00%
Donets’k	33996,4	215502	0,8987	0,9352	84,05%
Zhytomyr	178,3	4339	0,9995	0,9987	99,82%
Zakarpattia	190,9	1936	0,9994	0,9994	99,88%
Zaporizhzhia	6064,1	96144	0,9819	0,9711	95,36%
Ivano-Frankivs’k	3253,9	32948	0,9903	0,9901	98,05%
Kyiv	1618	25835	0,9952	0,9922	98,75%
Kirovohrad	21011,1	543298	0,9374	0,8368	78,44%
Luhans’k	2415,2	29838	0,9928	0,9910	98,39%

Lviv	10513,4	90869	0,9687	0,9727	94,22%
Mykolayiv	2223,6	48113	0,9934	0,9855	97,90%
Odessa	357,7	5004	0,9989	0,9985	99,74%
Poltava	968,7	19793	0,9971	0,9941	99,12%
Rivne	1300	22491	0,9961	0,9932	98,94%
Sumy	1501,7	32899	0,9955	0,9901	98,57%
Ternopil	40,2	529	0,9999	0,9998	99,97%
Kharkiv	1377,8	16123	0,9959	0,9952	99,11%
Kherson	46	1256	0,9999	0,9996	99,95%
Khmelnytsky	431,2	7006	0,9987	0,9979	99,66%
Cherkassy	319,4	5506	0,9990	0,9983	99,74%
Chernivtsi	416,6	3725	0,9988	0,9989	99,76%
Chernihiv	365,9	11523	0,9989	0,9965	99,55%
City of Kyiv	14818,7	4210	0,9558	0,9987	95,46%

Source: [State Statistics Committee of Ukraine]

As can be seen in Table 7, the highest concentration of waste per unit area and one person took place in the Dnipropetrovsk region. According to these indicators, it exceeded hundreds of times the level of pollution in other regions and significantly affected the average level of these indicators in Ukraine.

Also among the leaders of the anti-rating are Kirovograd, Donets'k, Lviv, Zaporizhia regions and the city of Kyiv. In contrast, minimal waste concentrations were observed in Ternopil, Kherson, Zakarpattia, and Zhytomyr regions.

Thus, today the problem of effective waste management, taking into account the criteria and constraints of the circular economy, is most relevant in the industrial regions of the country.

Summary, recommendations

Summing up, in order to form a closed ecological and economic cycle of Ukraine's processing industry, taking into account the existing specifics of functioning and development, it is necessary to actively implement the following measures:

1. The calculation of the generalized index of ecological and economic efficiency ($I_Г$ = 1,058) showed that in the processing industry during 2016-2018, there were favorable conditions for moderate economic growth, which was accompanied by a reduction in pollution of all kinds.

A positive result was achieved due to metallurgical production and mechanical engineering. Since the development and implementation of closed-loop technologies in production activities requires significant investment resources, the recommendations in this case are to maintain existing trends by intensifying and further implementing environmental measures.

2. The annual volume of waste generation in Ukraine in 2016-2018 increased from 295,870.1 thousand tons to 352,333.9 thousand tons. The main polluters were the mining and processing industries. Regarding processing enterprises, their waste generation decreased annually by 3.8% to 31,523.2 thousand tons. In the course of their lives, households annually generated only 1.6% of the total waste in Ukraine.

An important feature of waste generation is its territorial irregularity. The largest polluter is the Dnipropetrovsk region, where in 2018 this figure was 243,598.8 thousand tons, or 69.1% of all waste in Ukraine. Due to this, the total amount of waste accumulated in disposal sites in the Dnipropetrovsk region at the end of the reporting period was 82.6% of Ukraine's total. This is the result of activities in the extractive industry, which generates up to 87% of waste. In particular, the share of metal ore mining in their industry volume is 93.7%. Accordingly, the share of the processing industry is 9.1%. Thus, the implementation of measures to minimize waste generation only within the processing industry will not be able to radically solve the problem of this environmental disaster in the Dnipropetrovsk region. The solution can only be a comprehensive modernization of the entire economy, in particular, the extractive industry. In the short term, waste generation can be significantly reduced only by reorienting to foreign suppliers of raw materials and energy resources.

3. The circular economy pays considerable attention to waste recycling, namely, maximizing their reuse. Therefore, an important stage of the study was the management of the structure of waste use on the basis of a certain hierarchy of priorities in the "Golden Ratio" proportion. The largest share, exceeding 70%, was occupied by waste disposal in specially designated areas and only about 30% disposal. This situation has developed primarily due to the extraction of iron ore. The share of waste incineration for energy purposes and their placement in landfills was less than 1%.

The main reason for this unsatisfactory situation is the activity of the mining industry, in particular, the extraction of metal ores, due to which Ukraine annually generates more than 80% of all industrial and household waste. They include: residues of unextracted components, which may be up to 15-20% of the initial volume of extraction; oxidized quartzites; silicate and carbonate; natural stone and clay rocks; gravel and sand. Areas of possible use of these kinds of waste are: further processing and extraction of residual minerals at ferrous metallurgy enterprises, as building materials for the construction industry. However, given the use of outdated technologies, further processing is not economically viable. Therefore, in the long run, Ukraine's industry should reorient from the extraction and primary processing of resources to the production of high-tech products with a high share of added value, which will significantly reduce the volume of industrial waste. At the same time, the absolute volume and share of extractive industry products in total output in the economy should be reduced.

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