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STRATEGIC IMPERATIVES AND SOCIAL INNOVATIONS IN MANAGING PRODUCT ENVIRONMENTAL PERFORMANCE IN THE CONTEXT OF A CIRCULAR ECONOMY

The article demonstrates that the contemporary industrial landscape faces multifaceted environmental and social challenges arising from the increasing waste generation and negative environmental consequences for the population. In response, there is a pressing need to develop robust frameworks to enhance the environmental footprint of production in various industrial sectors. A key direction in addressing these challenges is a paradigm shift towards a circular economy – a model based on reducing waste generation and optimizing resource utilization through principles of reuse and recycling. Within the framework of the circular economy, effective management of the environmental productivity of goods and social innovations takes on paramount importance in order to reduce the negative environmental impacts of enterprises and enhance their resilience. This research is aimed at analyzing the socio-economic nuances of managing environmental productivity in the context of the circular economy and identifying strategic imperatives aimed at fostering sustainable industrial development. The research methodology involved a comprehensive analysis of data from 2016 to 2021, primarily focusing on the processing industry of Ukraine. Based on this analysis, trends and patterns regarding the dynamics of environmental productivity and waste generation in the sector were evaluated. The results underscore the relevance of collective efforts to optimize resource utilization in socio-economic terms and minimize waste generation. Calculation of the comprehensive efficiency index (IE = 1.063) revealed favorable conditions for moderate economic growth in the processing industry during the study period. This growth was accompanied by a reduction in pollution levels of all types, indicating the potential for sustainable development in this sector.

Keywords: *social innovations, circular economy, resource optimization, waste reduction, sustainable development, comprehensive approach.*

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СТРАТЕГІЧНІ ІМПЕРАТИВИ ТА СОЦІАЛЬНІ ІНОВАЦІЇ УПРАВЛІННЯ ЕКОЛОГІЧНІСТЮ ПРОДУКЦІЇ В УМОВАХ ЦИРКУЛЯРНОЇ ЕКОНОМІКИ

У статті доведено, що сучасний промисловий ландшафт стикається з багатогранними екологічними та соціальними викликами, що виникають внаслідок наростаючої генерації відходів та негативних екологічних наслідків для населення. У відповідь на це існує нагальна необхідність в розробці міцних рамок для покращення екологічного сліду виробництва в різних промислових галузях. Ключовим напрямом у вирішенні цих завдань є парадигмальний зсув до циркулярної економіки – моделі, що базується на зменшенні генерації відходів та оптимізації використання ресурсів за принципами повторного використання та переробки. У межах циркулярної економіки ефективне управління екологічною продуктивністю товарів та соціальні інновації набувають першорядного значення з метою зменшення негативних екологічних наслідків підприємств та підвищення їхньої стійкості. Це дослідження спрямоване на аналіз соціально-економічних нюансів управління екологічною продуктивністю у контексті циркулярної економіки та вияв-

лення стратегічних імперативів спрямованих на сприяння сталому промисловому розвитку. Методологія дослідження передбачала комплексний аналіз даних з 2016 по 2021 рік, переважно стосовно переробної промисловості України., на основі якого було оцінено тенденції та закономірності щодо динаміки екологічної продуктивності та генерації відходів у галузі. Результати підкреслюють актуальність спільних зусиль для оптимізації використання ресурсів соціально-економічному значенні та мінімізації генерації відходів. Розрахунок комплексного індексу ефективності (IE = 1,063) виявив сприятливі умови для помірного економічного зростання у переробній промисловості протягом досліджуваного періоду. Цей ріст супроводжувався зниженням рівнів забруднення всіх видів, що свідчить про потенціал для сталого розвитку у цій галузі.

Ключові слова: *соціальні інновації, циркулярна економіка, оптимізація ресурсів, зменшення відходів, сталий розвиток, комплексний підхід.*

Formulation of the problem. The contemporary industrial landscape grapples with multifaceted environmental challenges stemming from escalating waste generation and adverse ecological ramifications. In response, there is a compelling imperative to devise robust frameworks for enhancing the environmental footprint of products across various industrial domains.

A pivotal avenue in addressing these imperatives lies in the paradigm shift towards a circular economy – a model predicated on mitigating waste generation and optimizing resource utilization through principles of reusability and recycling. Within the ambit of a circular economy, the efficacious management of product environmental performance assumes paramount significance, aimed at curtailing enterprises' deleterious environmental impacts while bolstering their resilience.

In this research, we will explore the nuanced facets of managing product environmental performance within the framework of a circular economy, elucidating strategic imperatives geared towards fostering sustainable industrial development.

Analysis of recent research. In the contemporary economic landscape, linear consumption patterns have reached their thresholds. The concept of circular economy presents both operational and strategic advantages, manifesting across micro and macroeconomic domains. This paradigm holds substantial potential for fostering innovation, job creation, and fostering economic growth. Over the past 150 years of industrial evolution, a predominant linear model of production and consumption has prevailed, characterized by the extraction of raw materials, subsequent manufacturing, product utilization, and eventual disposal or incineration. Amidst escalating global economic instability and mounting signs of resource depletion, the imperative for a novel economic framework resonates ever more emphatically.

Circular economy, or closed-loop economy, is regarded by contemporary scholars as a pivotal aspect of the fourth industrial revolution. At its core lies the principle of secondary processing of any production, resulting in the minimization of waste from economic activities, significant reduction in natural resource consumption, and transition to renewable resources [1–3].

Analyzing the presented data, it can be noted that the concept of the Circular Economy (CE) is gaining traction as awareness grows regarding the need to transition from a linear economic model to a more balanced one in terms of resource management and waste production. The CE model is generally seen in the literature as a viable alternative for economic development that can mitigate the environmental damage caused by the linear economy. The goal is to move away from the "take–make–use–dispose" model by reintroducing waste into the production cycle through redesigning, recycling, and reusing.

Works by foreign scholars such as Abubakar I. R., Belmonte-Ureña L. J., Domenech T., Bahn-Walkowiak B., Droege H., Raggi A., Ramos T. B., Kennedy S., Linnenluecke M. K., Gregson N., Kirchherr J., Reike D., Hekkert M., MacArthur E., Garcia D. G., Kipnis E., Vasileiou E. and others make significant contributions to the understanding and development of the circular economy. They cover a wide range of aspects, from analyzing trends and perspectives on the development of the circular economy in different countries to examining conceptual and methodological issues, as well as legislative and organizational aspects of its implementation [4–11].

The objectives of this article are as follows. The aim of this article is to assess and manage the environmental characteristics of the products of the processing industry in the context of the circular economy using a model of intersectoral balance.

Presenting the main content. Assessment and management of the environmental performance of the recycling industry's products in this study were based on an input-output model adapted to address this task.

In the first stage, we studied the changes in the target indicator during 2016–2021 in comparable prices of the base year using the formula. Thus, if the final demand for food industry products increased by 1 million UAH, the corresponding pollution volumes were as follows:

– atmospheric emissions in 2016 amounted to 0.83 tons per 1 million UAH of final demand. In 2021, this indicator was 0.62 tons, resulting in a decrease of -26.2%, which is positive;

– carbon dioxide emissions in 2016 were 40.46 tons per 1 million UAH of final demand, while in 2021 it was 32.15 tons. The overall growth rate was -20.55%;

– waste generation in 2016 was 98.51 tons, and in 2021 it was 124.72 tons. Thus, we had a negative trend in the growth of the environmental indicator for this type of pollution by +26.6%;

– freshwater intake in 2016 was 2.70 thousand m^3 per 1 million UAH of final demand, and in 2021 it was 3.34 thousand m^3, an increase of +23.78%;

– water use in 2016 was 1.94 thousand m^3 per 1 million UAH of final demand, and in 2021 it was 1.98 thousand m^3, an increase of +1.4%.

Thus, the industry experienced mixed changes in the environmental performance of its products: the relative magnitude of atmospheric emissions showed a positive trend towards reduction, while waste generation and water usage exhibited an increasing trend.

The aggregated results of the calculations of product environmental performance indicators for all types of economic activities comprising the processing industry are presented (Table 1).

As seen from Table 1, the environmental performance of this sector during the study period generally exhibited

Table 1

The environmental performance of the processing industry in Ukraine according to the data from 2016 to 2021

Type of activity	Year	The environmental performance of production per 1 million UAH of additional final demand at base year prices				
		ЕК$_1$, тон	**ЕК$_2$, тон**	**ЕК$_3$, тон**	**ЕК$_4$, 10^3. м^3**	**ЕК$_5$, 10^3. м^3**
Food production	2016	0,834	40,464	98,514	2,695	1,944
	2021	0,616	32,151	132,587	3,336	1,978
	Growth rate, %	-26,19%	-20,55%	34,59%	23,78%	1,40%
Manufacture of coke and petroleum products	2016	1,588	65,234	335,989	1,999	1,555
	2021	1,184	52,790	434,135	1,552	1,164
	Growth rate, %	-25,46%	-19,08%	29,21%	-22,37%	-25,16%
Metallurgical production	2016	5,2	251,241	475,128	5,455	4,982
	2021	3,829	154,433	596,688	4,138	3,858
	Growth rate, %	-26,38%	-38,53%	25,58%	-24,14%	-22,57%
Other processing industry	2016	1,29	70,473	145,807	2,223	1,895
	2021	0,953	53,581	184,840	1,955	1,582
	Growth rate, %	-26,10%	-23,97%	26,77%	-12,05%	-16,53%

Source: Calculated by the authors based on data from [State Statistics Service of Ukraine]

positive trends. That is, pollution volumes per 1 million UAH of final production decreased. The exception was waste from economic activities, the relative size of which increased by 20-30% in the last two years. These negative changes were caused by an increase in waste generation in the extractive industry, whose output is actively consumed by the processing sector as raw materials.

Thus, there is an urgent need for the use of more environmentally friendly energy resources and a transition to alternative energy sources. The deterioration of the ecological-economic efficiency in the extractive sector, according to the diffusion effect, contributed to the deterioration of the environmental performance of production throughout the Ukrainian economy as a whole.

Within the developed concept and taking into account the conclusions drawn, three scenarios of possible eco-economic development of the processing industry were considered in the study. These scenarios envisaged a reduction in the dependence of processing enterprises on output from the extractive industry by -1%, -5%, and -10%, while maintaining existing production volumes. These changes are possible through the implementation of resource-saving technologies or by shifting to imported raw materials. The predicted improvement in the environmental performance of production occurs through the direct reduction of environmental damage at the resource and energy extraction stage.

Table 2 presents the results of a comparative analysis of these scenarios relative to the base year 2021.

Let's examine in more detail what the data from the calculations indicate, using the example of food production. The first scenario envisaged a reduction in dependence on raw materials from the extractive industry by -1%. As a result of these changes, the volume of atmospheric emissions per unit of production will decrease by 0.10%, carbon dioxide emissions by 0.02%, waste generation by 0.38%, and water intake by 0.01%. These changes are positive as they lead to an increase in the environmental performance of final product production. Similarly, the data from the second and third scenarios are interpreted.

As we can see, reducing the resource intensity of production should become a priority not only for the processing industry but also for other sectors on the path to a circular economy. "A comparative analysis of

Table 2

Results of scenario analysis: changes in pollution levels per unit of production in the processing industry

Activity Type	Scenario	Change in pollution levels per unit of production, %				
		ЕК$_1$	**ЕК$_2$**	**ЕК$_3$**	**ЕК$_4$**	**ЕК$_5$**
Food production	I	-0,10%	-0,02%	-0,38%	-0,01%	0,00%
	II	-0,51%	-0,07%	-1,90%	-0,02%	0,00%
	III	-1,02%	-0,14%	-3,82%	-0,05%	0,00%
Petroleum refining products manufacturing	I	-0,37%	-0,14%	-0,69%	-0,18%	-0,14%
	II	-1,86%	-0,68%	-3,44%	-0,92%	-0,69%
	III	-3,74%	-1,38%	-6,89%	-1,87%	-1,42%
Metallurgical production	I	-0,13%	-0,04%	-0,55%	-0,07%	-0,04%
	II	-0,63%	-0,22%	-2,78%	-0,35%	-0,20%
	III	-1,26%	-0,45%	-5,55%	-0,71%	-0,42%
Other processing industry	I	-0,12%	-0,02%	-0,47%	-0,02%	-0,01%
	II	-0,62%	-0,12%	-2,34%	-0,13%	-0,06%
	III	-1,22%	-0,24%	-4,70%	-0,26%	-0,11%

Source: developed by the author

activities (Table 2) indicates that the production of coke and petroleum products is the most resource-intensive. As a result, this area achieves the highest environmental benefit from the implementation of technologies related to increasing resource efficiency."

Conclusion. Summarizing, with the aim of forming a closed eco-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:

The calculation of the comprehensive eco-economic efficiency index (IE = 1.063) has shown that favorable conditions for moderate economic growth were formed in the processing industry during 2016–2021, accompanied by a reduction in pollution levels of all types.

Since the development and implementation of closed-cycle technologies in production activities require significant investment resources, the recommendations in this case are to maintain existing trends through the activation and further implementation of environmental measures.

The annual volume of waste generated from economic activities in Ukraine from 2016 to 2020 increased from 295,870.1 thousand tons to 456,423.8 thousand tons. The main polluters at the end of this period were the mining (85.7%) and processing (11.5%) industries. As for processing enterprises, their waste generation volume increased annually on average by +11.4% to 52,311.0 thousand tons. Households generated only 1.3% of the total waste volume in Ukraine during their activities.

An important feature of waste generation is its uneven distribution across regions. The most significant polluter of the environment is Dnipropetrovsk Oblast, where in 2020 this indicator amounted to 309,398.4 thousand tons, or 66.9% of all waste in Ukraine. As a result, the total volume of waste accumulated in disposal sites in Dnipropetrovsk Oblast at the end of the reporting period accounted for 72.6% of the total volume in Ukraine. This is the result of the mining industry's activities in the region, which generates up to 86% of the waste. In particular, the share of mining metallic ores from their sectoral volume is 93.4%. Thus, implementing measures to minimize waste generation only within the processing industry will not be able to fundamentally solve the problem of this ecological disaster in Dnipropetrovsk Oblast. The solution can only be achieved through a comprehensive modernization of the entire economy, including the mining sector. In the short term, significant reductions in waste generation can only be achieved by shifting to foreign suppliers of raw materials and energy resources.

Circular economy places significant emphasis on waste recycling, particularly on maximizing their reuse. Therefore, an important stage of the conducted research was the management of waste utilization structure based on the identified hierarchy of priorities using the "golden ratio" proportion. The largest proportion, approximately 70%, was allocated to waste disposal in specially designated areas, while approximately 22% was allocated to utilization. This situation arose primarily due to the extraction of iron ores. The share of waste incineration for energy production and their disposal in unauthorized landfills was less than 1%.

The main reason for this unsatisfactory state is the activity of the mining industry, particularly in the extraction of metallic ores, which annually accounts for more than 80.3% of the total industrial and household waste volume in Ukraine. These include: unselected component residues, which can account for 15-20% of the initial extraction volume; oxidized quartzites; silicate and carbonate; natural stone and clay rocks; gravel and sand. Possible uses for these wastes include further processing and extraction of residual minerals at metallurgical enterprises, as construction materials for the construction industry. However, under outdated technologies, further processing is economically unjustifiable. Therefore, in the future, Ukraine's industry should shift from resource extraction and primary processing to the production of high-tech products with a high value-added component, which will significantly reduce the volume of industrial waste generation.

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