UDC 330.341
JEL Classification: O44, O52
DOI: https://doi.org/10.20535/2307-5651.29.2024.308812

Trofymenko Olena
Doctor of Economic Sciences, Professor
ORCID ID: 0000-0002-2339-0377

Boiarynova Kateryna
Doctor of Economic Sciences, Professor
ORCID ID: 0000-0001-5879-2213

Kovalenko Bohdan
PhD Student
ORCID ID: 0009-0000-9953-6742

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Трофименко О. О., Бояринова К. О., Коваленко Б. О.
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського»

ANALYSIS OF THE INDICATORS AND PRECONDITIONS FOR STRATEGIC DEVELOPMENT OF THE CIRCULAR ECONOMY IN EU COUNTRIES

АНАЛІЗ ІНДИКАТОРІВ ТА ПЕРЕДУМОВ СТРАТЕГІЧНОГО РОЗВИТКУ ЦИРКУЛЯРНОЇ ЕКОНОМІКИ В КРАЇНАХ ЄС

The article is devoted to the study of approaches to the formation of circular economy indicators and the identification of the relationship between circular economy indicators and sustainable development in the EU-27. It assesses the effectiveness and interdependence of EU policies in promoting resource efficiency, waste management and sustainable practices. A correlation matrix was built on the basis of data for the period from 2008 to 2022, including indicators such as material footprint, waste generation, recycling rates, trade flows of recyclables and environmental impact. Based on the analysis of the correlation matrix, the relationships between the selected indicators and the key factors influencing the development of the circular economy were identified. The need for further integration and improvement of the EU's circular economy development policy is identified.

Key words: *circular economy, sustainable development, EU policy, resource efficiency, correlation analysis.*

Стаття присвячена дослідженню підходів щодо формування індикаторів циркулярної економіки та визначенню взаємозв'язків між показниками циркулярної економіки та сталого розвитку у ЄС-27. Оцінюється ефективність і взаємозалежність політик ЄС у сприянні ресурсоефективності, управлінню відходами та сталим практикам. На основі даних за період з 2008 по 2022 роки, включаючи такі показники, як матеріальний слід, утворення відходів, рівень переробки, торгівельні потоки вторинної сировини та вплив на навколишнє середовище, була побудована кореляційна матриця. Було проаналізовано динаміку окремих показників циркулярної економіки в ЄС-27. На основі аналізу кореляційної матриці було визначено взаємозв'язки між обраними показниками та ключові фактори впливу на розвиток циркулярної економіки. Зокрема, досліджено узгодженість обраних показників із директивами та політикою ЄС, зокрема, Дорожньою картою ресурсоефективності та Планом дій із циркулярної економіки. Встановлено високі кореляційні зв'язки та залежності між досліджуваними показниками, що вказує на складну взаємодію економічних, екологічних і політичних факторів у рамках циркулярної економіки ЄС. Зокрема, виявлено високу кореляцію між рівнем переробки та утворенням побутових відходів, а також між продуктивністю ресурсів і залежністю від імпорту матеріалів. Ці залежності підкреслюють важливість скоординованої політики для досягнення сталого управління ресурсами та забезпечення цілей циркулярності. Визначено необхідність подальшої інтеграції та вдосконалення політики розвитку циркулярної економіки в ЄС. Встановлено, що посилення узгодженості стратегій між секторами економіки може підвищити здатність ЄС реалізувати завдання щодо забезпечення економіки замкненого циклу. З врахуванням результатів проведеного аналізу індикаторів та передумов циркулярної економіки ЄС визначено, що ідентифікація взаємопов'язаності економічних показників та політик є ключовим для розробки ефективних стратегій сприяння сталому розвитку, ефективного використання ресурсів та економічного зростання.

Ключові слова: *циркулярна економіка, сталий розвиток, політика ЄС, ресурсоефективність, кореляційний аналіз.*

Problem statement. Today, the concept of the circular economy is gaining global popularity and is important for achieving the goals of the Paris Agreement. The circular economy is a new and inclusive economic paradigm focused on the design-oriented implementation of three main principles: minimising pollution and waste disposal, extending the life of products and promoting the widespread sharing of material and natural resources, and restoring natural systems. In March 2020, the European Commission adopted the Circular Economy Action Plan [1], which is an important part of the European Green Deal strategy. The aim of the Action Plan is to reduce consumption in

the EU and double resource efficiency over the coming decades, while contributing to economic growth. The Action Plan covers initiatives at all stages of the product life cycle, from design and production to use, repair, reuse, recycling and return to the economy. The new initiative includes the establishment of sustainability principles and rules to improve business processes to ensure a closed production cycle, reusability, repairability of products, and reduction of hazardous substances in products. The growing need for circular economy and sustainable development in the EU's political agenda necessitates studying the factors that influence its growth and identifying key measures to implement circular economy principles in production and commercial processes. There is a need to assess the clarity and coherence of EU policy in achieving circular economy goals, taking into account the key factors of circular economy development, which determines the relevance of this study.

Analysis of recent research and publications. Modern scientific research covers various areas of the circular economy. Paper [2] defines a system for assessing the causal relationships between the determinants of the transition to renewable production for the circular economy. An interesting approach to substantiating the 3R (Resource, Recycling, Results) model of the impact of circular economy innovations on the safety of industrial enterprises, used in [3], is the approach to substantiating the model of the impact of circular economy innovations on the safety of industrial enterprises. Paper [4] substantiated promising areas for the development of the circular economy in Ukraine on the example of solving the problem of reducing the negative anthropogenic impact on the environment. In particular, carbon dioxide emissions from different types of economic activity (EA) were considered. The use of the Shannon entropy-based estimation algorithm for modelling circular economy processes at the EU level was implemented in [5]. Paper [6] reveals new perspectives on understanding the internal nature of the circular economy, including the extension of the Sraffa pricing model in such a way that, despite the involvement of waste recycling, an economically justified profit will be obtained. In the study [7], a framework aimed at monitoring and optimising the circular efficiency of industrial products during their design and development process is developed and analysed to ensure and facilitate environmental trade-offs while meeting or anticipating end-of-life rules. In the paper [8], the authors propose a model for the formation of closed chains in a feedback logistics system. The analysis of scientific papers [1–8] shows the multidimensionality of the circular economy and the need to analyse the factors of its provision. At the same time, there is a lack of an integrated approach in research on the development of the circular economy, which would allow generalising the factors and indicators of its development and approaches to economic policy making into a single conceptual framework, which is the focus of this study.

Formulating the purposes of the article. The purpose of the article is to identify key factors and prerequisites for the development of the circular economy.

Methodology. The study was conducted in the following stages: 1) analyzing existing studies and approaches to the formation of circular economy indicators; 2) selecting key indicators of circular economy development in the EU-27; 3) using a correlation matrix to determine the relationships between indicators and identify key factors for circular economy development; 4) comparing the results of the correlation matrix analysis with key EU initiatives; 5) providing recommendations for circular economy development based on the results of the study.

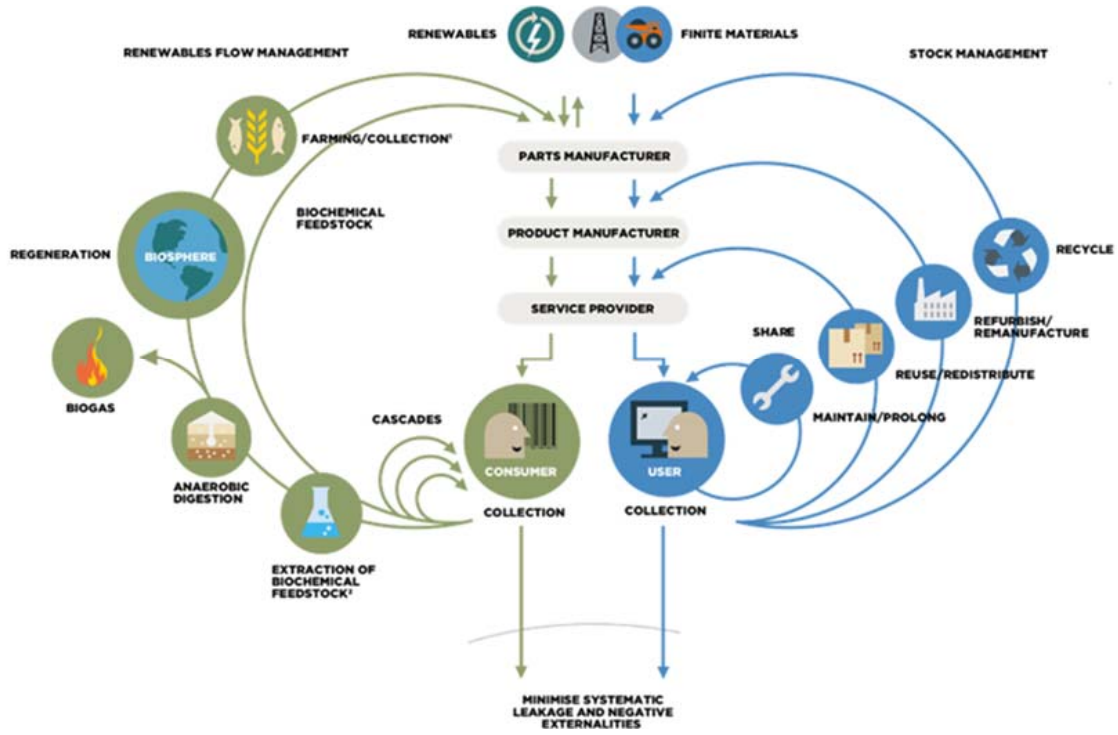
Presentation of the main research material. The circular economy is a new and inclusive economic paradigm focused on the design-led implementation of three main principles: minimising pollution and waste disposal, extending the life of products and promoting the widespread sharing of material and natural resources, and restoring natural systems [2–4]. The circular economy is defined as the opposite of the traditional linear economy and is part of the Fourth Industrial Revolution, aiming not only to optimise the use of resources but also to achieve rapid, systematic, transparent and predictable economic development, green decent jobs, responsible consumption and production. Given the multifactorial impact on economic development, this concept can be seen as an ideal model to strive for in reality.

Figure 1 shows the Ellen MacArthur Foundation's vision of a closed-loop flow of technical and biological materials, demonstrating the mechanisms of the circular economy. Thus, the circular economy is defined as the opposite of the traditional linear economy and is part of the Fourth Industrial Revolution, aiming not only to optimise the use of resources but also to achieve rapid, systematic, transparent and predictable economic development, green decent jobs, responsible consumption and production. Given the multifactorial impact on economic development, this concept can be seen as an ideal model to strive for in reality. The circular economy opens up the possibility of creating new business models, rethinking product consumption and changing consumer habits.

The European Academies' Science Advisory Council (EASAC) [10] notes that there are many indicators potentially relevant to the circular economy and proposes to group them in the areas of sustainability, environment, material flow analysis, social behaviour, organisational behaviour and economic productivity.

Eurostat uses a comprehensive approach to the construction of circular economy indicators. Eurostat's statistics include a block of indicators dedicated to the circular economy [11]. Such indicators as Material footprint, Generation of municipal waste per capita, Recycling rate of municipal waste, Circular material use rate, Imports from non-EU countries, Exports to non-EU countries, Intra EU trade, GHG emissions from production activities, Resource productivity, Material import dependency provide valuable insights into key areas of focus for EU policymakers and stakeholders. That is why we chose for research the main indicators from this block, which are presented in the Table 1.

Material footprint measures the global demand for materials used in the EU, including biomass, metal ores, minerals, and energy sources. It calculates the amount of raw materials needed to produce goods consumed within the EU. This indicator is crucial for understanding the EU's environmental impact, especially considering the Circular Economy Action Plan's focus on material footprints. It highlights the EU's responsibility for environmental pressures worldwide due to imported products.



Source: [9]

Table 1

Selected indicators of the circular economy

Indicator	Unit of measure	Classification
Material footprint	Tonnes per capita	Production and consumption
Resource productivity	Index 2000 = 100	Production and consumption
Generation of municipal waste per capita	Kg per capita	Production and consumption
Recycling rate of municipal waste	Percentage	Waste Management
Circular material use rate	Percentage	Secondary raw materials
Imports from non-EU countries	Thousand tonnes	Secondary raw materials
Exports to non-EU countries	Thousand tonnes	Secondary raw materials
Intra EU trade	Thousand tonnes	Secondary raw materials
GHG emissions from production activities	Kg per capita	Global sustainability and resilience
Material import dependency	Percentage	Global sustainability and resilience

Source: based on [11]

Resource productivity, indexed with a base year of 2000 set at 100, measures the efficiency of material use by dividing GDP by domestic material consumption (DMC). DMC includes raw materials extracted domestically plus imports minus exports, excluding upstream flows from outside the local economy. The EU Circular Economy Action Plan and Resource Efficiency Roadmap prioritize improving material productivity and reducing import dependency.

Generation of municipal waste per capita indicator measures waste managed by municipal authorities, primarily from households but also from commercial and public sources. In a circular economy, the focus is on reducing material waste while improving waste management practices. This includes promoting greener products, waste prevention, and following the Waste Framework Directive's priorities, starting with waste prevention and ending with environmentally safe disposal methods.

Recycling rate of municipal waste is a key metric tied to the EU Circular Economy Package and the Waste Framework Directive and measures the percentage of recycled municipal waste compared to total municipal waste generation. It includes material recycling, composting, and anaerobic digestion, reflecting how waste from final consumers is used as a resource in the circular economy.

Circular material use rate quantifies the proportion of recycled materials fed back into the economy, reducing the need for primary raw materials. It's calculated as the ratio of recycled materials to overall material use, including domestic material consumption and recycled materials. A higher circularity rate signifies a greater substitution of secondary materials for primary ones. The EU Circular Economy Package emphasizes the importance of circular material flows, making this indicator crucial for evaluating circular economy performance.

Imports from non-EU countries refers to the quantities of specific waste categories and by-products brought

into EU Member States from third countries. This data, sourced from Eurostat's International Trade in Goods Statistics, focuses on recyclable raw materials as defined by product codes in the Combined Nomenclature. Exports to non-EU countries represent the quantities of specific waste categories and by-products sent from EU Member States to third countries. Intra-EU trade tracks the volumes of specific waste categories and by-products traded between EU Member States. Monitoring these trade flows helps assess trends in secondary raw material markets and contributes to the EU's Raw Materials Scoreboard and Resource Efficiency Roadmap, providing insights into resource security and waste reduction efforts within the EU.

GHG emissions from production activities indicator quantifies greenhouse gas emissions from all production activities within the EU economy, excluding emissions from private households but including emissions from international air transport by EU airlines. It is measured in kilograms of CO2 equivalents per capita. This indicator is associated with the EU Sustainable Finance Action Plan and broader climate action and environmental protection policies aimed at reducing greenhouse gas emissions

Material import dependency indicator calculates the ratio of imports to direct material inputs, expressed as a percentage. It reflects the extent to which an economy relies on imports to fulfill its material requirements. A percentage of 100% indicates no domestic extractions during the reference period. It emphasizes the importance of a balanced approach combining domestic extraction, recycling, and imports to mitigate supply risks associated with high import dependency. The EU Circular Economy Action Plan and Resource Efficiency Roadmap prioritize improving resource productivity and reducing import dependency, making these indicator key for evaluating progress in resource management.

The values of these indicators for EU-27 for the period from 2008 to 2022 are presented in the Table 2. From 2008 to 2010, there was a notable decrease in material consumption, signaling potential efficiencies or shifts in consumption behaviors during that period. However, post-2010, the trend stabilized with minor fluctuations, indicating a need for further analysis into the factors influencing material consumption patterns in recent years. The total waste generation per capita data shows varying levels across the years but lacks a clear trend. Despite this variability, there is a slight decrease observed from 2018 to 2020, suggesting potential advancements in waste reduction strategies or changes in production and consumption dynamics.

The material footprint, representing the amount of raw materials used per capita, showcases a dynamic trajectory. Starting at 16.34 tonnes per capita in 2000, it peaked at 18.74 tonnes per capita in 2008 before gradually declining to 14.76 tonnes per capita by 2021. This fluctuating pattern hints at shifts in consumption patterns, influenced by economic conditions, technological advancements, and sustainability initiatives. In parallel, GHG emissions from production activities demonstrate a consistent downward trend. Beginning at 8.63 tonnes per capita in 2008, emissions decreased to 6.48 tonnes per capita in 2022. This decline suggests advancements in production processes, energy efficiency measures, and a move towards greener technologies and practices.

Private investments, measured as a percentage of gross domestic product (GDP) at current prices, fluctuated over the years. Starting at 0.9% in 2008, it experienced variations, reaching 1% in 2010 before returning to 0.7% in subsequent years, with minor fluctuations thereafter. The percentage of persons employed in the EU showcased a steady increase, rising from 1.8% in 2008 to 2.1% in 2021. This upward trend in employment signifies opportunities created within the circular economy sectors, such as renewable energy, waste management, and sustainable manufacturing, contributing to overall job growth and economic stability.

Gross value added (GVA), representing the economic value generated by sectors, saw incremental growth from 1.6% in 2008 to 2.2% in 2020 before a slight decrease to 1.7% in 2021. The rising GVA percentage indicates the growing importance and contribution of circular economy practices to overall economic value creation. Sectors emphasizing resource efficiency, waste reduction, and sustainable production methods are driving this trend.

Table 3 contains the results of building a correlation matrix. The correlation matrix provides a numerical representation of the relationships between pairs of indicators. The values in the matrix range from -1 to 1, where 1 indicates a strong positive correlation, -1 indicates a strong negative correlation, and 0 indicates no correlation. Positive correlations suggest that as one indicator increases, the other also tends to increase, while negative correlations suggest that as one indicator increases, the other tends to decrease. The correlations identified in the matrix are interpreted to understand the relationships between the various indicators.

Matrix shows strong negative correlation of Material footprint with Circular material use rate (-0.89) and Resource productivity (-0.79), indicating that as material footprint decreases, circularity and resource efficiency improve. Moderate positive correlation with Imports from non-EU countries (0.58) and GHG emissions from production activities (0.63), suggesting that material consumption may be influenced by external imports and production emissions.

Generation of municipal waste per capita has moderate positive correlation with Material footprint (0.47) and Imports from non-EU countries (0.59), indicating that waste generation may be influenced by material consumption and external imports. Weak positive correlation with Recycling rate of municipal waste (0.21), suggesting a minor influence on waste generation.

Recycling rate of municipal waste demonstrate strong negative correlation with Material footprint (-0.60) and Circular material use rate (0.85), highlighting that higher recycling rates are associated with lower material consumption and increased circularity.

Strong negative correlation with GHG emissions from production activities (-0.93), indicating that efficient recycling contributes to lower emissions.Strong negative correlation between Circular material use rate and Material footprint (-0.89) and GHG emissions from production activities (-0.83), emphasizing the importance of circularity in reducing material consumption and environmental impacts. Strong positive correlation with Resource productivity (0.96), indicating that higher circularity is linked to improved resource efficiency.

Table 2

The value of selected indicators of the circular economy for EU-27 from 2008 to 2022 [11]

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Material footprint, tonnes per capita (EU's Circular Economy Action Plan)	18,7	16,4	14,9	16,0	14,4	14,1	14,2	13,9	14,1	14,4	14,9	14,9	14,2	14,8	14,9
Generation of municipal waste, tones per capita (EU Waste Hierarchy and Circular Economy Package)	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Recycling rate of municipal waste, % (Circular Economy Action Plan and Waste Framework Directive)	36,6	37,3	38,0	38,9	40,9	41,5	43,4	44,9	45,9	46,3	46,4	47,2	48,7	49,8	48,6
Circular material use rate, percentage (EU Circular Economy Package)	9,2	10,4	10,7	10,2	11,0	11,2	11,1	11,2	11,4	11,5	11,6	11,3	11,6	11,4	11,5
Imports from non-EU countries, tonnes (EU's Raw Materials Scoreboard)	42,9	38,5	39,2	40,1	39,8	38,0	39,1	40,2	38,6	39,7	39,8	40,8	39,8	41,4	40,8
Exports to non-EU countries, tonnes (EU's Raw Materials Scoreboard)	26,9	32,5	33,4	34,8	36,6	32,9	33,9	30,6	35,0	36,6	36,9	35,6	36,7	37,6	36,5
Intra EU trade, tonnes (EU's Raw Materials Scoreboard)	76,2	67,4	75,9	80,1	81,5	79,2	81,6	80,4	81,2	84,7	85,4	84,7	83,1	91,5	86,5
GHG emissions from production activities, tones per capita (EU Sustainable Finance Action Plan)	8,6	7,9	8,0	7,9	7,7	7,5	7,2	7,3	7,3	7,4	7,2	6,9	6,2	6,5	6,5
Resource productivity, index 2000 = 100 (EU Circular Economy Action Plan and Resource Efficiency Roadmap)	104	113	118	114	123	126	126	129	132	132	132	134	132	134	138
Material import dependency, % (EU Circular Economy Action Plan and Resource Efficiency Roadmap)	21,9	20,9	22,7	22,0	22,8	23,0	23,0	23,9	24,2	24,1	24,3	23,7	22,2	22,6	22,4

Table 3

Correlation matrix of circular economy indicators

	Material footprint, tonnes per capita	Generation of municipal waste, tones per capita	Recycling rate of municipal waste, %	Circular material use rate, %	Imports from non-EU countries, tonnes	Exports to non-EU countries, tonnes	Intra EU trade, tonnes	GHG emissions from production activities, tones per capita	Resource productivity, index 2000 = 100	Material import dependency, %
Material footprint, tonnes per capita (EU's Circular Economy Action Plan)	1,00									
Generation of municipal waste, tones per capita (EU Waste Hierarchy and Circular Economy Package)	0,47	1,00								
Recycling rate of municipal waste, % (Circular Economy Action Plan and Waste Framework Directive)	-0,60	0,21	1,00							
Circular material use rate, percentage (EU Circular Economy Package)	-0,89	-0,14	0,85	1,00						
Imports from non-EU countries, tonnes (EU's Raw Materials Scoreboard)	0,58	0,59	0,11	-0,37	1,00					
Exports to non-EU countries, tonnes (EU's Raw Materials Scoreboard)	-0,61	0,17	0,68	0,77	-0,21	1,00				
Intra EU trade, tonnes (EU's Raw Materials Scoreboard)	-0,45	0,20	0,85	0,64	0,35	0,65	1,00			
GHG emissions from production activities, tones per capita (EU Sustainable Finance Action Plan)	0,63	-0,24	-0,93	-0,83	0,03	-0,70	-0,70	1,00		
Resource productivity, index 2000 = 100 (EU Circular Economy Action Plan and Resource Efficiency Roadmap)	-0,79	-0,04	0,94	0,96	-0,15	0,73	0,77	-0,88	1,00	
Material import dependency, % (EU Circular Economy Action Plan and Resource Efficiency Roadmap)	-0,59	-0,45	0,51	0,60	-0,14	0,28	0,52	-0,24	0,62	1,00

Imports show moderate positive correlations with Material footprint (0.58) and Generation of municipal waste (0.59), suggesting a connection between imported materials and waste generation. Exports display a strong positive correlation with Circular material use rate (0.77) and Intra EU trade (0.65), indicating that higher circularity and intra-EU trade may lead to increased exports.

Intra EU Trade has moderate positive correlation with Recycling rate of municipal waste (0.85), Circular material use rate (0.64), and Exports to non-EU countries (0.65), reflecting the interconnectedness of circular economy practices and trade within the EU.

Strong negative correlation between GHG emissions from production activities and Recycling rate of municipal waste (-0.93) and Circular material use rate (-0.83), indicating that efficient waste management and circularity contribute significantly to reducing production-related emissions. Moderate negative correlation with Material footprint (0.63), suggesting that lower material consumption is associated with lower emissions.

Resource productivity has strong positive correlation with Circular material use rate (0.96) and Recycling rate of municipal waste (0.94), highlighting that resource-efficient and circular practices lead to higher productivity. Strong negative correlation with Material footprint (-0.79) and GHG emissions from production activities (-0.88), indicating that improved resource productivity is linked to reduced material consumption and emissions.

Material import dependency shows moderate positive correlation with Generation of municipal waste (0.51) and Recycling rate of municipal waste (0.60), suggesting that material import dependency may influence waste generation and recycling efforts within the EU.

Overall, circular economy indicators such as Circular material use rate, Recycling rate of municipal waste, and Resource productivity exhibit strong correlations, indicating their interconnectedness in promoting sustainable resource management. Higher circularity is associated with reduced material footprint, efficient waste management, lower GHG emissions, and improved resource productivity. Trade dynamics (Imports, Exports, Intra EU trade) are influenced by circular economy practices, with higher circularity linked to increased exports and intra-EU trade. The correlation matrix underscores the importance of circular economy principles in achieving environmental sustainability, resource efficiency, and economic resilience within the EU.

It is also appropriate to compare the results regarding the relationships between the circular economy development indicators and key political initiatives.

In general, EU policy today is aimed at ensuring the growth of the circular economy. In the realm of environmental governance and sustainable development, the EU has been at the forefront, shaping policies and frameworks that steer the continent towards a more sustainable future through some of the pivotal EU documents and directives that have shaped the landscape of circular economy practices, waste management strategies, sustainable finance, and resource efficiency.

The EU's Circular Economy Action Plan [1], adopted in March 2020, stands as a testament to the Union's commitment to transitioning towards circularity. This comprehensive strategy outlines pathways for sustainable resource utilization, waste reduction, and the promotion of circular business models. It underscores the importance of innovation and collaboration in achieving a circular economy paradigm.

At the core of the EU's waste management framework lies the Waste Framework Directive (2008/98/EC) [12], a landmark legislation dating back to November 2008. This directive lays down the foundational principles of waste hierarchy, advocating for waste prevention, reuse, recycling, recovery, and environmentally safe disposal. It provides the legal backbone for Member States to enact robust waste management strategies aligned with circularity goals.

Aligned with the Waste Framework Directive is the EU Waste Hierarchy [13], a guiding principle that prioritizes sustainable waste management practices. It serves as a blueprint for Member States to design waste management plans that maximize resource efficiency, minimize waste generation, and promote circularity throughout the product lifecycle.

Building upon these foundational directives is the EU Circular Economy Package [14], introduced in December 2015 and revised in April 2020. This package encompasses a suite of legislative measures aimed at bolstering circularity, setting ambitious recycling targets, fostering eco-design initiatives, and encouraging sustainable consumption and production patterns.

The EU's Sustainable Finance Action Plan [15], launched in March 2018, marks a pivotal shift towards integrating sustainability into the financial sector. This strategic plan aims to mobilize private capital towards sustainable investments, promote green financing, and enhance transparency in environmental and social disclosures. It underscores the crucial role of the financial sector in driving sustainable development.

Complementing these initiatives is the EU Resource Efficiency Roadmap [16], unveiled in September 2011. This roadmap charts a course towards resource-efficient practices, emphasizing the need to reduce resource consumption, foster eco-innovation, and enhance competitiveness while mitigating environmental impacts.

Analysis of the correlation matrix in the context of the listed EU directives and policies shows a strong negative correlation between Material footprint and Resource productivity (-0,79) – this indicates that efforts to improve resource productivity, as outlined in the Resource Efficiency Roadmap, are associated with a reduction in the material footprint, aligning with the goals of the Circular Economy Action Plan.

Moderate positive correlation between Generation of municipal waste per capita and Recycling rate of municipal waste (0,21) suggests that higher waste generation may lead to higher recycling rates, reflecting the principles of waste hierarchy outlined in EU Waste Framework Directive and the Circular Economy Package.

Strong negative correlation between Recycling rate of municipal waste and GHG emissions from production activities (-0,93) implies that improved waste management practices, encouraged by directives like the EU Waste Hierarchy, Waste Framework Directive and Sustainable Finance Action Plan, can contribute to reducing greenhouse gas emissions from production activities.

Strong negative correlation between Circular material use rate and Material footprint (-0,89) indicates that as the circular material use rate increases (reflecting more efficient

resource use and recycling), the material footprint decreases, aligning with the objectives of the Circular Economy Package and EU's Circular Economy Action Plan.

Complex interdependencies among Imports from non-EU countries, Exports to non-EU countries, and Intra-EU trade show moderate to strong correlations with each other, reflecting the intricate dynamics of international trade in relation to resource efficiency and circularity goals. Imports from non-EU countries and Exports to non-EU countries show a strong positive correlation of 0.77, indicating a significant relationship between the volume of imports and exports involving non-EU nations. Intra-EU trade exhibits a moderate positive correlation with both Imports from non-EU countries (0.35) and Exports to non-EU countries (0.65), highlighting the interconnectedness of intra-EU trade activities with external trade flows. The strong positive correlation between Imports from non-EU countries and Exports to non-EU countries suggests that countries importing more also tend to export more, indicating an active trade engagement with non-EU partners. This aligns with EU directives aimed at fostering international trade relations while considering resource efficiency and circularity principles. The positive correlation between Intra-EU trade and both imports and exports indicates the role of internal EU trade in supporting resource-efficient practices. Efficient intra-EU trade mechanisms contribute to reducing environmental impact by optimizing logistical processes and minimizing resource wastage during transportation and trade activities. These correlations underscore the relevance of EU directives such as the Resource Efficiency Roadmap and the Circular Economy Action Plan. These directives promote sustainable resource management, circularity in trade practices, and efficient utilization of resources both within the EU and in its trade relationships with non-EU countries.

Based on the analysis of correlations and their alignment with EU directives, policy recommendations can be formulated. These recommendations include strengthening certain policies, addressing gaps or inconsistencies, promoting best practices, and encouraging further research and data collection to support evidence-based policymaking.

Conclusions. The European Union has made significant progress in promoting the transition to a circular economy and enhancing sustainability through various policies and directives. Despite the successes, there are also areas that require further attention and improvement.

The analysis of the correlation matrix showed strong connections and dependencies between the indicators, highlighting the complex interplay of economic, environmental and political factors within the EU circular economy. In particular, there are strong correlations between recycling rates and municipal waste generation, and between resource productivity and dependence on imported materials. These correlations underline the importance of coordinated policies to achieve the goals of sustainable resource management and circularity.

One of the strengths of EU policies is the comprehensive framework that addresses multiple aspects of the circular economy. Directives such as the Waste Framework Directive, the Circular Economy Action Plan, and the Resource Efficiency Roadmap have been instrumental in setting targets, promoting recycling, reducing waste generation, and improving resource efficiency. These policies have led to positive outcomes, such as increased recycling rates and a growing focus on sustainable production and consumption practices.

However, there are challenges and areas where EU policies can be enhanced. One of the key areas for improvement is the alignment and coherence of policies across different sectors and member states. While there are ambitious targets and initiatives at the EU level, implementation and enforcement vary among member states. Strengthening coordination and ensuring consistent implementation can enhance the effectiveness of circular economy policies. Additionally, there is a need to address certain gaps and shortcomings in current policies. For example, the circular economy can benefit from more emphasis on eco-design, product longevity, and sustainable consumption patterns. Policies that incentivize eco-design, promote repairability and durability of products, and encourage circular business models can further drive the transition to a circular economy. Moreover, while EU directives have made progress in waste management and recycling, there is room for improvement in addressing challenges such as plastic pollution, electronic waste, and hazardous waste management. Strengthening regulations, fostering innovation in recycling technologies, and promoting circular supply chains can help tackle these challenges more effectively. Strengthening coordination among member states, promoting sustainable design and consumption, and addressing specific waste streams are key areas where EU action can make a lasting impact on advancing the circular economy agenda.

References:

1. A new Circular Economy Action Plan. EUR-Lex – Access to European Union law. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

2. Khan S., Ali S. S., Singh R. (2022). Determinants of Remanufacturing Adoption for Circular Economy: A Causal Relationship Evaluation Framework. *Applied System Innovation*. № 5(4). P. 62. DOI: https://doi.org/10.3390/asi5040062

3. Kuzior A., Arefieva O., Vovk O., Brożek P. (2022). Innovative Development of Circular Systems While Ensuring Economic Security in the Industry. *Journal of Open Innovation*. № 8(3). P. 139–139. DOI: https://doi.org/10.3390/joitmc8030139

4. Kyzym M. O., Khaustova V. Y., Shpilevskyi V. V., Shpilevskyi O. V. (2023). A Substantiation of Promising Directions for the Development of Circular Economy in Ukraine. *The Problems of Economy*. 2023. № 3(57). P. 101–111. DOI: https://doi.org/10.32983/2222-0712-2023-3-101-111

5. Busu C., Busu M. (2018). Modeling the Circular Economy Processes at the EU Level Using an Evaluation Algorithm Based on Shannon Entropy. *Processes*. № 6(11). P. 225. DOI: https://doi.org/10.3390/pr6110225

6. Emmenegger J.-F, Chable D., Nour Eldin H. A., Knolle H. (2020). Sraffa and Leontief Revisited: *Mathematical Methods and Models of a Circular Economy*. Available at: http://dspace.nbuv.gov.ua/handle/123456789/173146

7. Saidani M., Kim H., Yannou B., Leroy Y., Cluzel F. (2019). Framing product circularity performance for optimized green profit. *HAL Archives Ouvertes*. Available at: https://hal.science/hal-02270135

8. Kovtun T. (2020). A model of closed circuits forming in a logistics system with feedback. *Innovative Technologies and Scientific Solutions for Industries*. № 4(14). P. 113–120. DOI: https://doi.org/10.30837/itssi.2020.14.113

9. Elli MacArthur Foundation: Circular economy systems diagram. Available at: https://www.ellenmacarthurfoundation.org/circular-economy-diagram

10. The European Academies Science Advisory Council. Available at: https://easac.eu/

11. Eurostat – Circular economy – Monitoring framework. European Commission. Available at: https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework

12. Directive – 2008/98 – EN – Waste framework directive – EUR-Lex. EUR-Lex – Access to European Union law. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32008L0098

13. Waste hierarchy – EUR-Lex. EUR-Lex – Access to European Union law. Available at: https://eur-lex.europa.eu/EN/legal-content/glossary/waste-hierarchy.html

14. Circular Economy Package. European Commission. Available at: https://commission.europa.eu/eu-regional-and-urban-development/topics/cities-and-urban-development/priority-themes-eu-cities/circular-economy-cities_en

15. EU Sustainable finance strategy. Climate-ADAPT. Available at: https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/eu-sustainable-finance-strategy

16. Roadmap to a Resource Efficient Europe COM (2011). European Environment Agency. Available at: https://www.eea.europa.eu/policy-documents/com-2011-571-roadmap-to