The object of this study is the process of circular transformations in the context of technology transfer.

It has been proven that circular transformations in the context of technology transfer are a new challenge in the global directions of harmonization of economic processes. The relevance of the study is determined by the fact that the development of technologies, in particular "green" technologies under modern conditions has become a catalyst for changes in production, consumption, and management of resources, which contributes to the achievement of the goals of sustainable development of enterprises. This involves focusing on the formation and support of social integration of the production sector and society, reducing emissions into the environment, and ensuring the balanced development of business entities at different levels of management.

The characteristics of the level of circular transformations in the countries of the world were studied. The relationship between technology transfer and circular transformations was established through indicators of the degree of greening of the economy. A SWOT analysis of circular transformations was conducted to identify key opportunities and threats that would affect the business environment. A model for evaluating the effectiveness of circular transformations has been built. Based on the proposed model, the GDP change forecast for the EU countries for 2023–2027 was calculated. Carbon dioxide emission trends were predicted under optimistic and pessimistic scenarios, which made it possible to justify the need to transition to a carbon-neutral model of economic development and the feasibility of implementing "green" technologies. The transition to a new model of economic development will allow for optimal management of depleted resources, wider use of resource-saving technologies and will reduce pressure on the environment

Keywords: circular transformations, technology transfer, business entity, sustainable development, performance evaluation model

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BUILDING A MODEL FOR EVALUATING THE EFFICIENCY OF CIRCULAR TRANSFORMATIONS IN THE CONTEXT OF TECHNOLOGY TRANSFER

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1. Introduction

Uncertainty has given rise to new challenges and tasks, especially in the system of ensuring man-made safety, sustainable development at all levels of management of the modern economy, in particular of business entities. This led to the development of various mechanisms for its provision, which involve a combination of technology transfer and scientific cooperation with the aim of implementing a green transition. The introduction of the latest "green" technologies is a necessary condition for achieving long-term sustainability guidelines in the functioning of business entities in the conditions of increased competition. This is confirmed by the research of the British think tank Ember and the

German institute Agora Energiewende [1]; in 2020 the EU for the first time produced more electricity from renewable sources than from fossil fuels. The share of wind and solar energy production is about 60 % in the Scandinavian countries. At the same time, it is necessary to take into account that the implementation of "green" technologies involves significant costs both for the development of the latest technologies and their transfer. According to the estimates of the Ministry of Ecology of Ukraine, up to 8 % of Ukraine's GDP and about a third of budget revenues should be allocated to annual investments in climate transformations [2].

The development and implementation of "green" technologies cannot be considered exclusively as a search for certain technical solutions.

Circular transformations of the business cycle in the context of technology transfer and modernization of existing regulatory mechanisms and production are prerequisites for the implementation of a new model of sustainable development under modern conditions. The European "green" trend is implemented through climate commitments under the Paris Climate Agreement, green economic transformations, energy efficiency, etc.

The interaction between the concepts of circular transformations and technology transfer creates synergy and contributes to the solution of complex problems related to sustainable development, environmental protection, and improvement of the standard of living of the population. Technologies are a catalyst for changes in production, consumption, and resource management, which contributes to achieving the goals of sustainable development of enterprises. At the same time, as noted by UNCTAD experts, "passing the green technological wave" is based on green technologies and Industry 4.0 technologies. They will have long-term negative consequences for both individual enterprises and national economies as a whole [3]. At the same time, the presence of an effective system for the introduction of innovations in the field of information and digital, biotechnologies and nanotechnologies increases the potential ability of the countries of the world to take an active part in the processes of Industry 4.0 [4].

Based on the above, research on the justification of circular transformations in the context of technology transfer and the construction of an economic-mathematical model of its effectiveness is relevant. This will make it possible to study the trends of changes in GDP as a whole and carbon dioxide emissions in particular with an orientation towards sustainable development of the country.

2. Literature review and problem statement

The idea of circular transformations originates in China and the European Union. Under modern conditions, this concept is quite relevant and is becoming more and more widespread, as it allows business entities at different hierarchical levels to reduce the negative impact on the environment and close the product life cycle [5, 6]. Circular transformations contribute to the emergence of new technologies aimed at saving resources, significantly reducing environmental risks at various levels of management, increasing the welfare of society, ensuring sustainable development and social justice.

Innovative "green" technologies aimed at reducing waste or converting waste into valuable products are attractive for investment. Thus, according to [7], "green" technologies from 2011 to the first quarter of 2016 were financed in the amount of 668 million dollars, with the largest share being material processing. As stated in [7], "waste collection and sorting are undergoing significant changes owing to innovations based on software, data analysis, and robotics." Such innovative products include a citizen engagement platform to reduce waste through data analytics, such as the Trashbot innovation that involves sorting waste and recyclables, etc. Such innovative products provide robotization of waste processing processes.

The problems of technology transfer and their influence on the efficiency of circular transformations have been studied by many scientists. Thus, researchers in paper [8] stated that the depletion of resources, the growing unpredictability of changes in the social and economic environment "create pressure" on the development of technologies and their transfer as a factor of ensuring sustainable development. At the same time, it would be necessary to pay more attention to the social consequences of technology transfer, as it can have both positive and negative effects on efficiency, in particular circular transformations and the level of GDP.

In [9] it is stated that more and more innovations and technology transfer have a negative impact on the environment, which is becoming a serious problem. At the same time, technology transfer is usually considered within the boundaries of individual countries or regions. However, the impact on the environment cannot be limited to the borders of individual countries, so it is necessary to consider the issue of technology transfer within continents, in particular in Europe. This will also allow analyzing its impact on changes in macroeconomic indicators, first of all GDP.

Reducing the severity of this problem and researching environmental innovations became the basis of the Europe 2020 strategy, which defines smart, sustainable, and inclusive growth technologies to increase production productivity and ensure the competitiveness of the economy. Researchers in [10] showed that in countries that have a surplus of resources, the growth of the "green" economy is inhibited due to the "innovation effect" and the "effect of the transfer of technical leadership". But the questions of how to ensure green economic growth in such countries and stimulate innovation in the manufacturing sector remain unresolved. Also, the problem of the influence of infrastructure on the volume of "green" innovations requires additional research, which will make it possible to highlight innovative technological solutions.

Study [11] focuses on "green" investments as a stimulus for economic recovery after the COVID-19 pandemic. At the same time, it remained unclear which technological trends in the "green" economy will contribute to the growth of the economies of different countries, as well as how the pandemic affected the transfer of technologies. It also requires additional research to outline the conditions for the effective implementation of circular transformations in the context of technology transfer.

Paper [12] analyzed the possibilities of development of green technologies in the post-crisis period. It was determined that the corona crisis led to the appearance of long-term and short-term consequences for the environment. Thus, the emphasis is on the slowing down of the processes of globalization and the corresponding reduction in the volume of carbon-intensive industries. However, issues of circular transformations, including in the context of technology trans-

fer, are hardly considered. The problem of developing "green" proposals that will allow the economy to move to more sustainable development also needs additional attention.

In study [13], it is noted that the consequences of COVID-19 led to the need to change the strategy of the development of business entities, in particular, in terms of the introduction of modern technologies. However, the authors do not provide criteria for the formation of strategies for the development of business entities in the conditions of circular transformations.

Work [14] analyzed the implementation of the UN sustainable development goals in practice, identified three key directions: implementation (implementation of goals), monitoring (monitoring, assessment, and revision), finance (increase of global financial flows). The authors note that this approach will contribute to the growth of the development potential in the geographical aspect, individual business entities, as well as state and non-state institutions. However, it remained unclear what circular transformations should take place and what their intensity should be to ensure the goals of sustainable development.

Paper [15] notes that the green economy has become an important political basis for sustainable development in both developed and developing countries. It forms the basis for creating a more resource-efficient, low-carbon, less environmentally harmful society. At the same time, one of the reasons for the slow circular transformation is the existence of different concepts underlying the "weak", "transformational" and "strong" green economy. This complicates the possibilities of quantitative studies of the processes of circular transformations. However, the paper does not offer "useful indicators" or effective methods of assessing the impact on the development of the "green" economy and forecasting the effectiveness of circular transformations.

Paper [16] analyzes program documents on the green transformation of primary industries in Norway. It is noted that green transformations, in particular circular ones, are used by various entities to achieve their own goals, which should be taken into account when evaluating the feasibility and effectiveness of such transformations. At the same time, it is necessary to pay more attention to their potential dark sides. However, it remained unclear which methods should be used to evaluate the effectiveness of transformational processes.

Study [17] considered the dependence of the sustainable development of the economy on the innovative and creative potential of the economy. The authors note that the basis of the country's innovative competitiveness should be knowledge and research results, as well as higher education institutions as catalysts for the development of innovative approaches, new or innovative technologies. At the same time, the factors of formation of innovative and creative potential and the influence of these factors on the intensity of circular transformations remained unexamined.

Work [18] states that the development of innovative cooperation under the conditions of circular transformations depends on the ability of managers to quickly react and adapt to changes in the external environment. This predetermines the need to combine the principles of global cooperation, identify the key imperatives of sustainable development, and search for innovative measures under the conditions of the circular economy. At the same time, the authors did not pay attention to the problem of quantitative and qualitative assessment of the effectiveness of the implementation of these imperatives.

Our review of the literature [8–18] demonstrates that the problems of technology transfer and circular transformations to ensure the goals of sustainable development have not been sufficiently developed. This problem is complicated by the fact that the study of the influence and interrelationship of circular transformations, sustainable development in the context of technology transfer to build a model of the effectiveness of circular transformations requires a comprehensive approach.

Therefore, there is a need to conduct research aimed at comprehensively highlighting the place of circular transformations in the context of technology transfer, their components, as well as determining the quantitative assessment of the effectiveness of circular transformations. Results will make it possible to substantiate the transition of the economy to a new carbon-neutral development model.

3. The aim and objectives of the study

The purpose of our study is to build a model for evaluating the effectiveness of circular transformations in the context of technology transfer. This will make it possible to take into account the influence of individual components of circular transformations in the context of technology transfer and justify the feasibility of transitioning the economy to a new carbon-neutral, resource-efficient development model. This, in turn, will contribute to the definition of a rational state policy aimed at establishing the interaction of the state, business, science, and society in the context of technology transfer and the introduction of innovations to solve a wide range of technical, economic, and environmental problems.

To achieve the goal, it is necessary to solve a number of tasks, namely:

– to investigate the relationship between technology transfer and circular transformations and the degree of greening of the economy of the countries of the world;

– to evaluate the impact of factors of circular transformations in the context of technology transfer on changes in GDP;

– to make a forecast of changes in GDP for EU countries and justify the transition of the economy to a carbon-neutral development model through circular transformations.

4. The study materials and methods

The object of our study is the process of circular transformations in the context of technology transfer. The subject of the research is a set of methodological principles, theoretical-methodical and scientific-practical recommendations regarding circular transformations in the context of technology transfer.

In the course of the research, a set of general scientific and special methods of cognition was used. The methods of system analysis and synthesis and generalization were applied to study the relationship between technology transfer and circular transformations and highlight the meaning of circular transformations, characteristics of the current state and trends in the implementation of "green" technologies. When clarifying the components of circular transformations, abstract logical methods were applied. Methods of comparative analysis were used to analyze new renewable energy sources, greenhouse gas emissions, and the level of GDP in European countries, as well as the global index of

the "green" economy. Economic and mathematical methods were employed to build a model for evaluating the effectiveness of circular transformations in the context of technology transfer, forecasting changes in EU countries' GDP, and carbon dioxide emissions based on pessimistic and optimistic scenarios. Graph-analytical methods were used for visual representation of research results and graphical interpretation of statistical data.

5. Research results related to circular transformations in the context of technology transfer

5. 1. Research on the relationship between technology transfer and circular transformations and the degree of greening of the world economy

The deepening of globalization trends in the modern world determines the importance of technology transfer, the purpose of which is to provide access to the latest technologies to increase the efficiency (improvement) of production or product quality. This will make it possible to carry out circular transformations, namely the replacement of a "linear" model with a "circular" one. It should be noted that technology transfer can be aimed at different goals depending on the purpose and needs of society. It can be implemented through energy-saving technologies aimed at reducing energy use and increasing the energy efficiency of production. Technologies of automation and intelligent production make it possible to optimize processes and increase production efficiency. The introduction of renewable energy technologies is aimed at reducing dependence on traditional energy sources and promotes sustainable development. Technologies of digital transformations make it possible to improve management, interaction with customers and optimize business processes. Also, the introduction of technologies, the use of which makes it possible to process waste and reduce the negative impact on the environment (production with low carbon dioxide emissions). In addition to the above, technology transfer can be used in medicine and education. From the point of view of cooperation and partnership, technology transfer contributes to the establishment of international partnership and cooperation, which ensures the exchange of knowledge and experience. The relationship between technology transfer and circular transformations is shown in Fig. 1.

It is obvious that the development and implementation of technologies allows for the development of high-tech industries, contributes to the development of new products and, as a result, increases the efficiency and competitiveness of enterprises and the economy as a whole. The principal guidelines of technology transfer and circular transformations are the use of alternative energy sources, the introduction of smart technologies, the greening of the transport sector, the extension of the product's useful life, the use of secondary raw materials. Technology transfer will contribute to the implementation of circular practices in production and rational use of resources to ensure sustainable development.

One of the directions of circular transformations is the use of "green" technologies in the construction industry, in particular due to recycling or reuse of materials, possible savings and significant cost savings, as well as reducing environmental pressure.

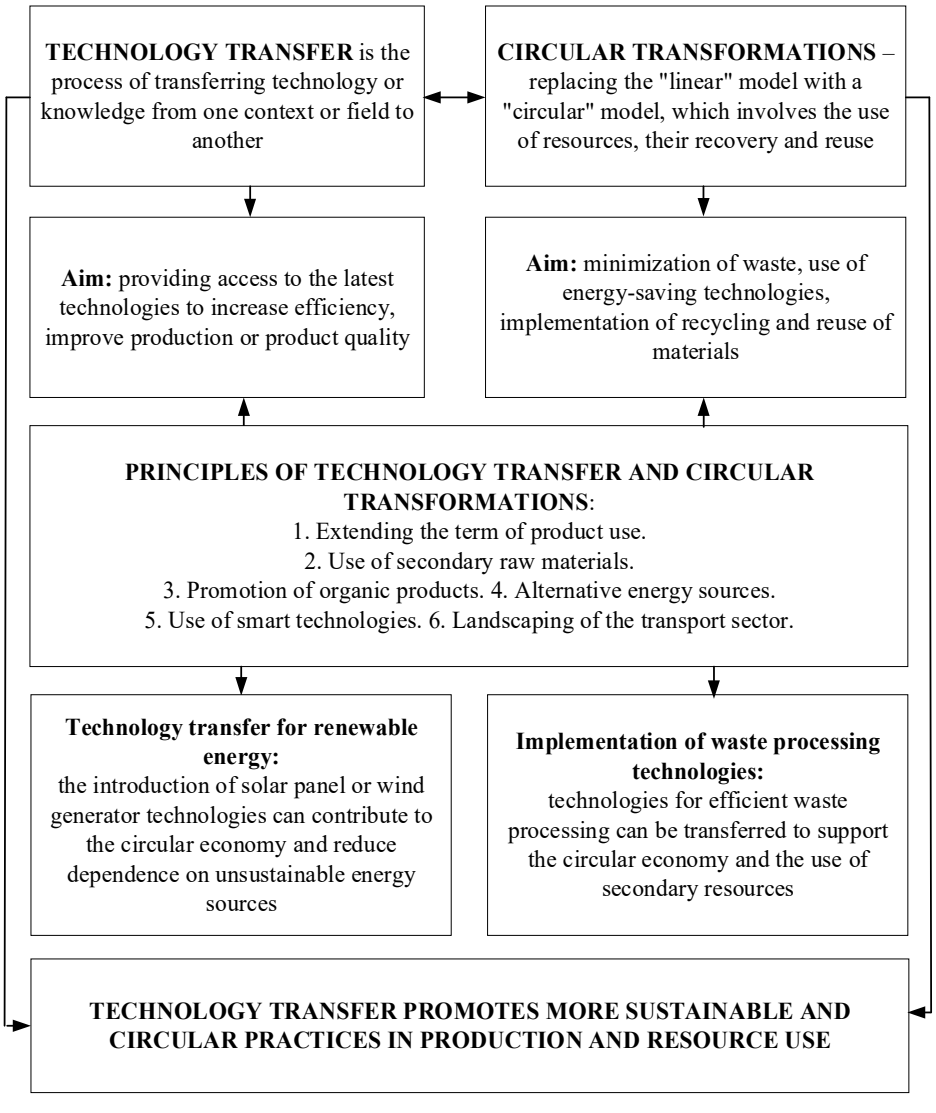

Fig. 1. The relationship between technology transfer and circular transformations

The fact of the interrelationship of technology transfer, circular transformations with the goals of sustainable development (SDG) of Ukraine is obvious. In particular, technology transfer is linked to SDG 10 "Reducing Inequality" because technology transfer from developed countries to developing countries can reduce technological inequalities

and contribute to sustainable development. Water treatment technologies can be transferred to ensure access to clean water in line with SDG 6 "Clean water and adequate sanitation". Regarding circular transformations, the connection with SDG 12 "Responsible consumption and production", SDG 13 "Climate change mitigation", SDG 14 "Conservation of marine resources", and SDG 15 "Protection and restoration of terrestrial ecosystems" should be noted. Circular transformations are aimed at reducing waste and efficient use of resources. Also, reducing the use of new types of raw materials and introducing recycling can help reduce greenhouse gas emissions. This should be taken into account when planning the development of settlements and territories, as well as when planning and managing them with the participation of the public, which corresponds to SDG 11 "Sustainable development of cities and communities" [19]. The main SDGs related to innovative technologies and the target values of individual indicators are given in Table 1.

Thus, circular transformations in the context of technology transfer imply an "ecology-economy" relationship and are a condition for ensuring the principles of sustainability in the development of an entrepreneurial entity. It is this approach that contributes to balancing by solving a number of problems, namely energy problems, providing the population with organic products, etc. Also, in order to slow down the depletion of resources, it is necessary to introduce resource-saving technologies into production and optimally manage them.

Table 1

National tasks, indicators, and targets in accordance with the goals of sustainable development

Task	Indicator	Target values by year		
		2020	2025	2030
SDG 6 «Clean Water and Sanitation»				
6. 3. Reduce the volume of untreated wastewater discharge, primarily with the use of innovative water treatment technologies at the state and individual levels	6. 2 .3. Share of discharges of polluted (polluted without treatment and insufficiently treated) wastewater into water bodies in the total volume of discharges, %	13	10	5
SDG 7 «Affordable & Clean Energy»				
7. 1. Expand infrastructure and modernize networks to ensure reliable and sustainable energy supply based on the introduction of innovative technologies	7. 3 .1. Heat losses in heating networks, %	18	14	12
7. 4. Increase the energy efficiency of the economy	7. 4. 1. Energy intensity of GDP (primary energy expenditure per unit of GDP), kg equivalent per 1 USD 2011 purchasing power parity	0.2	0.17	0.14
SDG 8 «Decent Work and Economic Growth»				
8. 1. To ensure sustainable GDP growth based on the modernization of production, the development of innovations, increasing export potential, and the introduction of products with a high share of added value to foreign markets	8. 1. 4. Ukraine's place in the ranking according to the Global Innovation Index	50	45	40
8. 2. To increase the efficiency of production on the basis of sustainable development and the development of high-tech competitive industries	8. 1 .2. Return on fixed assets	0.26	0.35	0.45
SDG 9 «Industry, Innovation & Infrastructure»				
9. 2. Ensure the expansion of the use of e-vehicles and the associated infrastructure network	9. 1 .2. Share of electric transport in domestic traffic, %	65	70	75
9. 5. To create a financial and institutional system (innovation infrastructure) that will ensure the development of scientific research and scientific and technical (experimental) developments	9. 5. 2. Share of innovative products sold in the volume of industrial products, %	5	10	15
SDG 11 «Sustainable development of cities and communities»				
11. 2. To ensure the development of settlements and territories exclusively on the basis of integrated planning and management with the participation of the public	11. 1 .2 Share of regions that have approved and implemented regional development strategies and action plans for their implementation, developed with public participation, %	100	100	100
11 .5. Reduce the negative impact of pollutants, including on the environment of cities, through the use of innovative technologies	11. 5. 1. Volume of emissions of pollutants into the atmosphere, % to the level of 2015	data are expected		
SDG 12 «Responsible consumption and production»				
12. 1. Reduce the resource intensity of the economy	12. 1 .1. Resource intensity of GDP (share of the value of natural resources per unit of GDP), % to the level of 2015	90	80	60
SDG 14 «Conservation of marine resources»				
14. 1. Reduce marine pollution	14. 1 .1. Share of polluted wastewater discharges in the total volume of discharges into the marine environment, %	11	9	5
14. 3. Introduce effective regulation of the extraction of marine bioresources	14. 1 .3. Volumes of legal extraction of marine bioresources in the exclusive maritime zone of Ukraine, thousand tons	36	38	40

Continuation of Table 1

SDG 15 «Protection and restoration of terrestrial ecosystems»				
15. 1. Ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems	15. 3 .1. Share of the area of the territories of the national ecological network in the total territory of the country, %	39	40	41
15. 2. Promote sustainable forest management	15. 2 .2. Stocks of trees in forests, million cubic meters	2,200	2,300	2,400
15. 3. Restore degraded lands and soils using innovative technologies	15. 1 .3. Number of identified and implemented tasks to achieve a neutral level of land degradation, units	Data are expected		
	15. 2 .3. Area of arable land (arable land), thousand hectares hectare	31,150.9	29,760.8	28,370.7
SDG 17 «Partnership for Sustainable Development»				
17. 1. Mobilize additional financial resources by encouraging investment from foreign and domestic investors	17. 2 .1. Net inflow of foreign direct investment (according to the balance of payments), USD billion	10	16	17.5
17. 3. Develop partnerships between government and business to achieve the Sustainable Development Goals	17. 1 .3. Number of public-private partnership projects, units	15	30	45

Source: compiled by Authors on the basis of [19].

The conditions of circular transformations and sustainability of development are interconnected and aimed at the integration of development and environmental protection; activation of the processes of social integration of the individual and society. It should be noted that sustainability in development is considered as the success of circular business transformations. The combination of technological, economic, and environmental problems is a global driver of sustainable development of countries and individual enterprises.

The volume and intensity of technology transfer, both at the level of individual enterprises and the national economy, mostly depends on a number of factors.

First of all, readiness for the introduction of the latest technologies should be analyzed. Thus, according to the Index of readiness for advanced technologies in 2023, the top ten countries include the USA, Sweden, Singapore, Switzerland, Liechtenstein, the Netherlands, South Korea, Germany, Finland, China, and Belgium. Ukraine occupies the 58th position out of 166, having lost 5 positions in two years [3]. Fig. 2, 3 show the dynamics of registration of inventions by Ukrainian and foreign owners by technical direction.

Analysis of the information illustrated in Fig. 2, 3 reveals that in general for 2019–2022 there is a decrease in registered inventions by both Ukrainian owners and foreign ones in technical areas. The total amount of inventions in 2022 is 1,566 units, of which 40.22 % belong to Ukrainian owners, respectively, in 2021, only 2,298 units (43.08 %), in 2020 – 2,179 units, (49.84 %), in 2019 – 2255 units. (55.34 %). The reasons for this situation are the COVID-19 pandemic and the full-scale military aggression of the Russian Federation against Ukraine. However, it should be noted that over the course of four years, inventions from the technical direction "Chemistry" accounted for the largest share, followed by "Mechanical engineering".

In Ukraine, there is a trend towards technology transfer, which is characteristic of the vast majority of developing countries. Thus, the number of inventions registered by Ukrainian owners in 2021 is 24.3 %, and in 2022 by 32.7 % less than those registered by foreign owners.

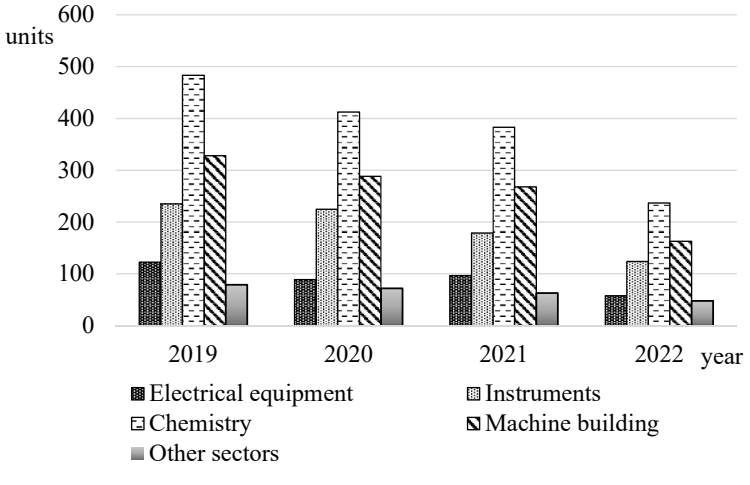

Fig. 2. Dynamics of registration of inventions by Ukrainian owners by technical areas, units
Source: compiled by Authors based on [20]

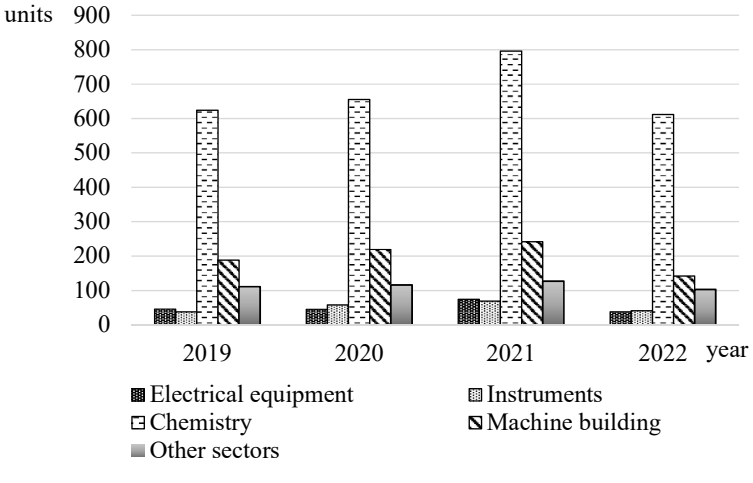

Fig. 3. Dynamics of registration of inventions by foreign owners by technical areas, units
Source: compiled by Authors based on [20]

Another factor affecting the volume and intensity of technology transfer is the expectation of financial results. As can be seen from Fig. 4, in Ukraine, the profitability of enterprises that carried out technology transfer was 116.6 % in 2019, and 107.7 % in 2021. Even in 2022, it was 99.1 %. This shows that companies are interested in the transfer of technologies because in addition to the social effect, there is also a financial effect.

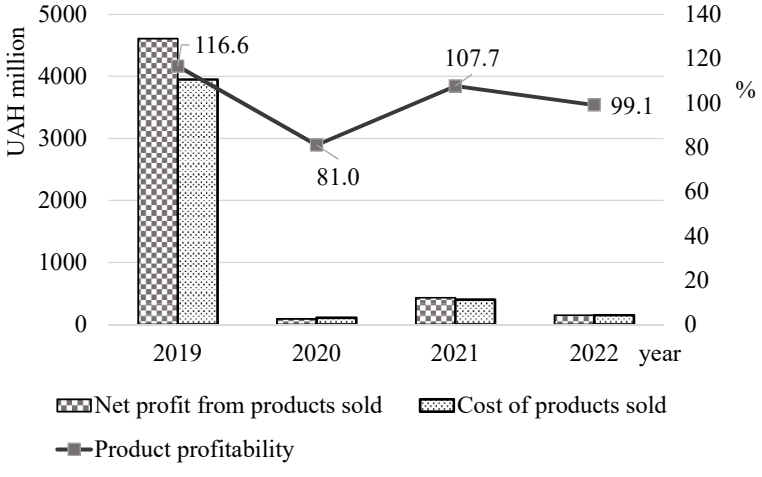

Fig. 4. Dynamics of financial results of enterprises, institutions, and organizations that carried out technology transfer, for 2019–2022
Source: compiled by Authors based on [21]

Ukraine's desire for European integration and the implementation of EU standards make it possible to focus on the trends that have developed in the EU countries in the direction of circular transformations and technology transfer.

The main goals of the European Green Course are the transition of European countries to reducing the level of greenhouse gas emissions, improving the welfare of citizens, protecting biodiversity, and greening the economy [22]. The key guidelines of the European Green Course are clean energy, climate action, construction and reconstruction, sustainable industry, sustainable mobility, pollution reduction, biodiversity, sustainable agricultural policy [23].

In order to highlight the goals and objectives of implementing the principles of green growth, we shall examine the data reflecting the degree of greening of the economy. The dynamics of new renewable energy sources in Europe for 2010–2020 show that the development of renewable generation is taking place. Renewable energy sources have increased to 38.5 % in 2021 from 22.13 % in 2010, making it one of Europe's energy sources. Fig. 5 shows the ranking of the leading countries according to the Global Index of Environmental Efficiency in 2022.

The degree of circular transformations, in particular the effectiveness of green technologies in the world economy since 2010, is measured using the Global Green Economy Index developed in 2010 by the DUAL Citizen agency. When calculating the index, climate changes, priority, efficiency of the economy, investments, and the environment are taken into account [25]. The index is the basis for the creation of separate systems for measuring the sustainability and "greenness" of world economies.

Another index is the Low Carbon Economy Index, developed by Price Waterhouse Coopers in 2000. The index measures the G20's progress in reducing carbon emissions. The indicator is defined as the ratio of carbon to GDP for a year, and its result is influenced by such factors as energy efficiency, fuel consumption, population density, the structure of the country's economy, and the state of the climate system [7].

The Global Cleantech Innovation Index, which was devised in 2012, is linked to the environment. The index is calculated on the basis of a weighted assessment of the available resources and conditions for attracting innovations and the achieved practical results of their implementation.

A comprehensive indicator of the quantitative assessment and comparative analysis of the environmental policy of states and their individual subjects is the Environmental Efficiency Index, which makes it possible to determine the country's place in accordance with the ecological health and sustainability of the system (Fig. 5). Thus, according to the GGEI rating, which reflects the level and degree of use of green technologies in 180 countries of the world, Denmark takes the leading position in 2022. The first five also include Switzerland, Iceland, Norway, Finland, that is, the Scandinavian countries, which indicates their interest in the application of circular transformation technologies.

Fig. 6 shows the relationship between greenhouse gases and the level of GDP of EU countries for 2010–2021, so greenhouse gas emissions tend to decrease with a slight increase in GDP.

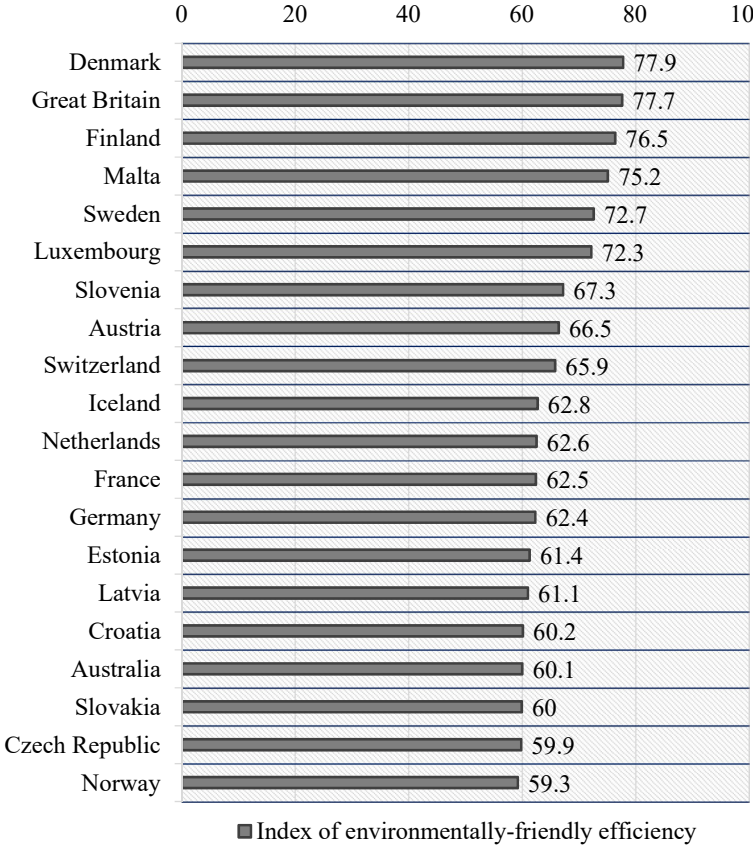

Fig. 5. Ranking of the leading countries according to the Global Index of Environmental Efficiency in 2022
Source: compiled by Authors based on [24]

In general, for the period of 2010–2021, the total GDP of the EU countries increased by almost 2 %, and the total emissions decreased by almost 24 %.

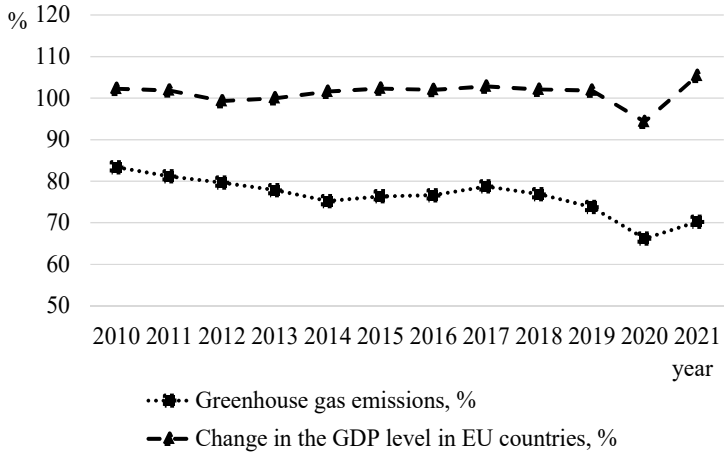

Fig. 6. Dynamics and relationship between greenhouse gas emissions and GDP of EU countries for 2010–2021, %
Source: compiled by Authors on the basis of [26]

5. 2. Assessment of the impact of factors of circular transformations in the context of technology transfer on changes in GDP

To assess the prospects of circular transformations, an expert survey of scientists, businessmen, and representatives of state and local authorities was conducted. 40 experts were interviewed. Strengths and weaknesses, prospects and threats of circular business transformations were determined, the impact of which was assessed on a 5-point scale. The following scale was used: 1 point – minimal impact, 2 points – insignificant impact, 3 points – significant impact, 4 points – significant impact, 5 points – maximum impact. The results of the survey are given in Table 2.

As can be seen from Table 2, regarding the issue of circular transformations, experts attach more importance to the issues of opportunities and threats that will accompany economic activity in the future. And in this context, the following three characteristics are of particular importance:

1. Opportunities to attract and the scope of innovations for the introduction of "green" technologies, their financial efficiency and riskiness determine their attractiveness for business.

2. Economic efficiency of the eco-industry, which is one of the most important criteria for the success of entrepreneurs.

3. The possibility of creating additional jobs to reduce the level of unemployment, which can be considered as one of the factors of reducing tension in society.

To evaluate the impact of these factors on the efficiency of circular transformations, the following indicators were selected:

1. Eco-innovation index (eco-innovation index), which characterizes the effectiveness of environmental innovations in the creation of a public product through the improvement of resource efficiency indicators.

2. Value added in eco-industry (value added in eco-industry), which shows the economic contribution, created added value in the sector of ecological goods and services due to the use of eco-innovations.

3. Employment in the environment (employment in the environment), which characterizes the activity of a part of the population in the creation of a public product using eco-innovations and resource management.

Table 2

SWOT analysis of evaluation of circular transformations in the context of technology transfer

Strengths	Point-based estimate	Weaknesses	Point-based estimate
Reorientation to a carbon-neutral model of economic development	5	Insufficient technological capacities	5
Increasing the level of man-made safety	5	Limited sources of financing for innovative projects in the field of circular transformations	5
State support for innovative projects in the field of circular transformations	4	A long period of implementation of innovative projects	4
Growth of business profits	3	Low competence of employees in the field of circular transformations	2
Increasing the level of social responsibility	4	Imperfect legislation in the field of circular transformations	3
Growing consumer confidence	3	Low level of "environmental culture" among enterprises and consumers	4
Opportunities	Point-based estimate	Threats	Point-based estimate
Increasing the efficiency of the use of renewable and non-renewable resources	5	The need for additional consumption of resources during recycling	4
Increasing business competitiveness	5	Lack of information about potential benefits from the implementation of circular economy models	2
Increasing cooperation with other companies in the field of technology transfer	4	Unprofitable in the short term	4
Inflow of innovations in related sectors of the economy to ensure reuse of materials and products	3	Unforeseen changes in legislation	5
The possibility of attracting foreign funding, grants and the public-private partnership mechanism	3	Deterioration of financial stability of companies	4
Intensification of the development of "green" technologies	4	Temporary deterioration of the quality of processed products	3
Growth of GDP and the number of jobs	2	Increasing instability in the external and internal socio-economic environment of the country	5
Reducing pressure on the environment	4	Low predictability of the future effect	4

The effectiveness of circular transformations will be reflected in the GDP indicator, which characterizes the total market value of final goods and services produced on the territory of a certain state for the reporting period (most often a year).

A model for evaluating the effectiveness of circular transformations has been built in the following form:

$$GDP = a_0 I_{ei}^{a_1} V_{ei}^{a_2} PE_{ei}^{a_3}, \quad (1)$$

where *GDP* is the efficiency of circular transformations due to changes in gross domestic product (GDP);

I_{ei} – eco-innovation index;

V_{ei} – added value in eco-industry;

PE_{ei} – employment of the population in the environment;

a_0 – total factor productivity (technological coefficient);

a_1, a_2, a_3 – coefficients of elasticity according to selected factors.

The study of the impact of circular transformations on GDP was carried out on the basis of empirical data for the EU for 2014–2022 (Table 3).

Table 3

Empirical data on the EU for 2014–2022 for calculating model parameters (1)

Year	GDP growth, %	Eco-innovation index, %	Added value in the eco-industry, %	Employment of the population in the environment, %
2014	101.6	103.5	103.4	104.0
2015	102.3	105.3	102.7	100.0
2016	102.0	106.2	97.3	92.8
2017	102.8	107.9	100.0	97.4
2018	102.1	109.4	103.4	97.1
2019	101.8	111.1	103.4	95.6
2020	94.3	112.4	104.7	97.6
2021	105.4	115.8	108.1	102.4
2022	103.5	121.5	108.1	104.7

Source: compiled by Authors on the basis of [27, 28].

Determining the parameters of model (1) using the least squares method involves bringing it to a linear form using the logarithm procedure. Then model (1) will take the form:

$$\ln GDP = \ln a_0 + a_1 \ln I_{ei} + a_2 \ln V_{ei} + a_3 \ln PE_{ei}, \quad (2)$$

where $\ln GDP$, $\ln I_{ei}$, $\ln V_{ei}$, $\ln PE_{ei}$, $\ln a_0$ are natural logarithms of the efficiency of circular transformations, eco-innovation index, value added in eco-industry, employment in environmental, and total factor productivity, respectively.

To determine the coefficients a_0, a_1, a_2, a_3, the following system of equations was solved:

$$\begin{cases} n\ln a_0 + a_1 \sum \ln I_{ei} + \\ +a_2 \sum \ln V_{ei} + a_3 \sum \ln PE_{ei} = \sum \ln GDP, \\ a_0 \sum \ln I_{ei} + a_1 \sum (\ln I_{ei})^2 + a_2 \sum (\ln I_{ei} \ln V_{ei}) + \\ +a_3 \sum (\ln I_{ei} \ln PE_{ei}) = \sum (\ln I_{ei} \ln GDP_{ei}), \\ a_0 \sum \ln V_{ei} + a_1 \sum (\ln V_{ei} \ln I_{ei}) + a_2 \sum (\ln V_{ei})^2 + \\ +a_3 \sum (\ln V_{ei} \ln PE_{ei}) = \sum (\ln V_{ei} \ln GDP_{ei}), \\ a_0 \sum PE_{ei} + a_1 \sum (\ln PE_{ei} \ln I_{ei}) + \\ +a_2 \sum (\ln PE_{ei} \ln V_{ei}) + a_3 \sum (\ln PE_{ei})^2 = \\ = \sum (\ln PE_{ei} \ln GDP_{ei}), \end{cases} \quad (3)$$

where n is the number of years for which data are taken to calculate the model.

As a result of solving the system of equations (3) based on the data from Table 2, the following dependence of change in GDP on selected factors was obtained:

$$GDP = 0.987 I_{ei}^{0.590} V_{ei}^{0.671} PE_{ei}^{0.521}. \quad (4)$$

The correspondence of the built model to the actual trends and relationships was evaluated using the coefficient of determination in MS Excel. The coefficient of determination is 0.740, that is, the influence of the selected factors on the change in GDP, which is described by model (4), is statistically significant.

As can be seen from model (4), all selected factors have a significant direct impact on the change in GDP. The biggest impact is on the factor "value added in eco-industry", which is expected. Thus, if the added value in the eco-industry increases by 1 %, the total GDP will increase by 0.671 %. With an increase in the volume of eco-innovation (eco-innovation) by 1 %, GDP will increase by 0.590 %, and with an increase in employment in this area by 1 %, GDP will increase by 0.521 %. This proves the need for circular transformations, which will have not only a social effect but also an economic one, which will contribute to further development.

5. 3. Forecast of changes in GDP after circular transformations in the context of technology transfer

Based on model (4), the forecast of change in GDP for the EU for 2023–2027 was determined (Fig. 7).

As can be seen from Fig. 7, due to circular transformations, annual GDP growth will average 0.3 **%**. Therefore, the development and implementation of a set of measures regarding the use of "green" technologies is of particular relevance. The non-coincidence of breaks in the actual and estimated schedule for the period 2016–2019 is explained by the presence of random factors, the influence of which is leveled in the model.

Table 4 gives information on changes in GDP and carbon dioxide emissions for 2010–2019.

For 12 years, there has been a reduction in carbon emissions per unit of manufactured product. The dynamics of global CO_2 emissions show that the world economy has reached a critical level of carbon saturation. But recently, the growth of carbon dioxide emissions in the world for some years is ahead of the GDP growth (primarily due to China, India, Russia, Japan). This process is getting bigger and bigger every year, creating a threat to socio-economic development for a number of countries [30].

The method of exponential smoothing was used to construct a forecast of carbon dioxide emissions based on the initial information (Table 4). The results of calculations for forecasting the dynamics of carbon dioxide emissions for the next 2024–2030 years are given in Table 5.

A graphical representation of the scenarios regarding the forecast of carbon dioxide emissions is shown in Fig. 8. The coefficient of determination (R^2) was used to assess the statistical significance of the determined dependence, which was 0.8232, which indicates the correspondence of the model to the real process.

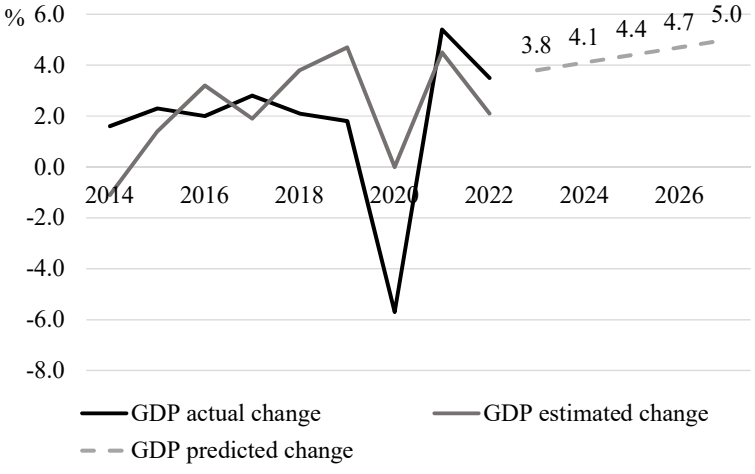

Fig. 7. The dynamics of changes in the GDP of the EU countries in 2014–2027

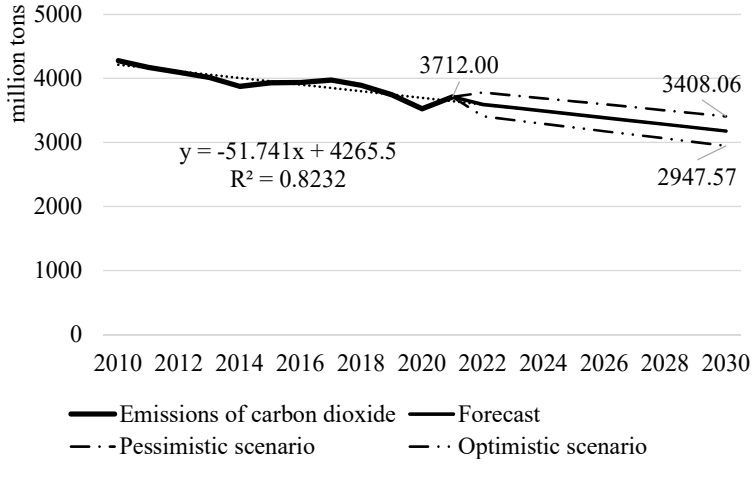

Fig. 8. Dynamics of carbon dioxide emissions for 2010–2030

Table 4

Emissions of carbon dioxide per unit of GDP in EU member states

Year	GDP increase (decrease), %	CO_2 emissions, million tons	CO_2 emissions per GDP unit, kg CO_2/$
2010	2.249	4,277	0.47
2011	1.858	4,172	0.47
2012	–0.707	4,095	0.46
2013	–0.032	4,013	0.46
2014	1.576	3,877	0.44
2015	2.311	3,930	0.43
2016	2.008	3,939	0.42
2017	2.814	3,974	0.41
2018	2.066	3,892	0.41
2019	1.819	3,743	0.40
2020	–5.68	3,526	0.40
2021	5.39	3,712	0.40

Source: compiled by Authors based on [29].

The reduction of carbon dioxide emissions shows that green innovations, technologies, and investments will contribute to the sustainability of economic development and reorientation to a carbon-neutral model. Such a transition should be accompanied by a change in state policy, the search for additional sources of funding for "green" technologies through cooperation and cross-sectoral integration.

Table 5

Forecast of carbon dioxide emissions for 2024–2030

Year	Forecast of CO_2 emissions, million tons	Pessimistic scenario	Optimistic scenario
2024	3,489.71	3,688.04	3,291.38
2025	3,437.72	3,641.61	3,233.84
2026	3,385.74	3,595.08	3,176.40
2027	3,333.76	3,548.45	3,119.07
2028	3,281.78	3,501.74	3,061.82
2029	3,229.80	3,454.94	3,004.66
2030	3,177.81	3,408.06	2,947.57

The results of forecasting changes in the general trend of reducing carbon dioxide emissions indicate optimistic indicators. However, no forecast is able to take into account unforeseen circumstances that could radically change the balance of forces and the effectiveness of the socio-economic system.

Circular transformations in the context of technology transfer will lead to the balancing of the economy and the transition to a new qualitative state within Industry 4.0, owing to which the potential for further innovative development and the emergence of new "green" technologies appears. This will cause an increase in aggregate gross value added; total employment in the sectors of production of organic products, export of ecological products, etc.

Technology transfer promotes the development of new sectors of the economy, especially in developing countries, where the introduction of new technologies can be a catalyst for innovation and expansion of sectors that were previously less developed. The use of resource-saving technologies ensures an increase in production productivity, and as a result, an increase in production volumes and an improvement in product quality. If the transfer of technology takes place from developed countries to developing countries, it can contribute to the reduction of technological and economic inequalities between different regions of the world. Technologies aimed at the use of renewable resources, energy and environmentally clean production can contribute to sustainable development and reduce the negative impact on the environment. Technology transfer can contribute to strengthening international relations and cooperation, as it involves the participation of different countries in solving common challenges and problems. However, it is important to consider that the success of technology transfer depends on the adaptation, support, and ability of recipient countries to effectively use and develop the transferred technologies.

6. Discussion of research results on circular transformations in the context of technology transfer

The results of our study of the processes of circular transformations in the context of technology transfer testify to the following. Ensuring the ecological and technogenic

security of the country is possible through the construction of a new model of a carbon-neutral economy that is resource-efficient. The study proved the relationship between technology transfer and circular transformations (Fig. 1). It is noted that technology transfer can be aimed at various goals depending on the purpose and needs of society. In particular, it can be implemented through energy-saving technologies, technologies of automation and intelligent production, technologies of renewable energy. As for digital transformations, they are aimed at improving management, improving interaction with clients, and optimizing business processes. Therefore, technology transfer will contribute to the implementation of circular practices in production and rational use of resources to ensure sustainable development. The relationship between technology transfer, circular transformations, and the goal of sustainable development is also outlined. That has made it possible to single out the condition of ensuring the principles of sustainability in the development of the business entity as "ecology-economy".

In addition to the above, attention should be paid to the fact that the integration of economic, environmental, and social problems is a global driver of sustainable development of countries and individual enterprises. This fact is confirmed by the fact that according to the Index of readiness for advanced technologies as a factor of the volume and intensity of transfer, in 2023 Ukraine occupies the 58th position out of 166. However, in 2021 and 2022, 5 positions were lost, which is explained by military actions on the territory of Ukraine. During 2019–2022, there is a decrease in registered inventions in technical areas by both Ukrainian and foreign owners (Fig. 2, 3). The reasons for this situation are the COVID-19 pandemic and the full-scale military aggression of the Russian Federation against Ukraine. Another factor affecting the volume and intensity of technology transfer is the expectation of financial results (Fig. 4). European countries are on course for a green transition, which indicates the degree of greening of the production sector. In particular, in 2021, the development of renewable energy sources as one of Europe's energy resources is observed, the value of which has increased to 38.5 % compared to 2010. A change in the global index of the green economy by country was also recorded, with Sweden and Switzerland remaining the leaders, which confirms their focus on the wide use of resource-saving technologies. The dynamics of the Environmental Efficiency Index, which is used to rank the countries of the world according to the ecological health and sustainability of the system (Fig. 5), illustrate the interest in the application of circular transformation technologies. This is recorded in such countries as Denmark, Sweden, Switzerland, Iceland, Norway, Finland.

One of the problems is greenhouse gas emissions, therefore it is necessary to modernize the existing model of the economy with an emphasis on a new resource-efficient one. The relationship between greenhouse gases and the level of GDP for 2010–2021 was analyzed, so greenhouse gas emissions tend to decrease with a slight increase in GDP (Fig. 6). Overall, over the period 2010–2021, total EU GDP grew by almost 2 %, and total emissions fell by almost 24 %.

The SWOT analysis of circular transformations made it possible to identify key opportunities and threats that will affect the business environment (Table 2). The following three characteristics are of particular importance:

1. Opportunities to attract and the scope of innovations for the introduction of "green" technologies, their financial efficiency and riskiness determine their attractiveness for business.

2. Economic efficiency of the eco-industry, which is one of the most important criteria for the success of entrepreneurs.

3. The possibility of creating additional jobs to reduce the level of unemployment, which can be considered as one of the factors of reducing tension in society.

The peculiarities of the study are that the efficiency of circular transformations and technology transfer of the production sphere, the result of which are changes in GDP, is described using a model. The eco-innovation index, added value in the eco-industry, and employment of the population in the environment were proposed and used as factors influencing efficiency. The influence of selected factors on the change in GDP, which is described by the developed model, is statistically significant. The coefficient of determination is 0.740, the selected factors have a significant direct impact on the change in GDP. The biggest impact is on the factor "value added in eco-industry", which is expected. Thus, if the added value in the eco-industry increases by 1 %, the total GDP will increase by 0.671 %. With an increase in the volume of eco-innovation (eco-innovation) by 1 %, GDP will increase by 0.590 %, and with an increase in employment in this area by 1 %, GDP will increase by 0.521 %. This approach to building a model for evaluating the effectiveness of circular transformations in the context of technology transfer has advantages, as it allows determining the degree and direction of influence of individual factors on the resulting indicator (GDP). This proves the need for circular transformations, which will have not only a social effect but also an economic one, which will contribute to further sustainable development.

Forecasting of changes in GDP for EU countries for 2023–2027 was carried out (Fig. 7), which once again confirms the need to develop and implement a set of measures for the use of "green" technologies. Changes in GDP, CO_2 emissions, CO_2 emissions per unit of GDP were analyzed (Table 4). For 12 years, there has been a reduction in carbon emissions per unit of manufactured product. Therefore, attention should be paid to the fact that the world economy has reached a critical level of carbon saturation, which poses a threat to the socio-economic development of a number of countries. A forecast of carbon dioxide emissions was built using the exponential smoothing method. The results of the forecast indicate optimistic indicators (Table 5, Fig. 8) and confirm that green innovations, technologies, and investments will contribute to the sustainability of economic development and reorientation to a carbon-neutral model.

The advantages of this work in comparison with studies [8–18] are that the relationship between circular transformations and technology transfer has been investigated, as well as indicators reflecting the degree of greening have been analyzed. This became the basis for choosing macroeconomic indicators, namely the change in GDP, as an indicator of the effectiveness of circular transformations and technology transfer in the production sphere.

The peculiarities of the obtained results are that the transition of the economy to a carbon-neutral model of development and the feasibility of implementing "green" technologies are substantiated. This allows us to move to a new qualitative state and ensure the harmonious development of society. The results can be used in the development of the country's sustainable development strategy with an emphasis on circular transformations in the context of technology transfer.

The limitations of the research are a certain subjectivity of the factors chosen as model parameters (eco-innovation

index) and the difficulty of obtaining reliable and up-to-date statistical information on added value in the eco-industry and employment of the population in the environment. This limits the possibility of obtaining verified model parameters.

The need to adjust the developed model in terms of taking into account the specificity of the production sector of an individual country, the achieved level of circular transformations and the specificity of technology transfer can be considered a drawback.

Further research should be aimed at determining the conditions for the acceleration of technology transfer and circular transformations, at researching the processes of raising "consciousness" regarding the introduction of "green" technologies among business entities.

7. Conclusions

1. It is shown that there is a significant relationship between technology transfer and circular transformations, which is manifested in the promotion of the development of high-tech industries, the emergence of new products, and the reduction of the negative impact on the environment. This affects the level of efficiency and competitiveness of enterprises and the economy as a whole. It has been established that the principal guidelines of technology transfer and circular transformations are the extension of the product's useful life; use of secondary raw materials; promotion of organic products; Alternative Energy Sources; use of smart technologies; greening of the transport sector. Attention is focused on the fact that circular transformations are a driver of sustainable development, and this contributes to the emergence of new high-tech industries, the introduction of sustainable and circular practices in production and use of resources. Technology transfer also contributes to the establishment of international partnerships and cooperation, which ensures the exchange of knowledge and experience.

2. It has been proven that the volume of innovations for the introduction of "green" technologies, the economic efficiency of the eco-industry and the possibility of creating additional jobs play a key role in the effectiveness of the transformation. To determine the influence of factors, a model was built for evaluating the effectiveness of circular transformations in the context of technology transfer, which showed that they have a significant direct impact on the change in GDP. The biggest impact is on the factor "value added in eco-industry". If the added value in the eco-industry increases by 1 %, the total GDP will increase by 0.671 %. With an increase in the volume of eco-innovation (eco-innovation) by 1 %, GDP will increase by 0.590 %, and with an increase in employment in this area by 1 %, GDP will increase by 0.521 %. Thus, circular transformations will have both social and economic effects.

3. A forecast of changes in GDP for EU countries for 2023–2027 was suggested. The forecasting results indicate that under the conditions of successful circular transformations in the context of technology transfer, annual GDP growth will be an average of 0.3 %. The established relationship between the change in GDP and carbon emissions showed that, under the optimistic scenario, they will decrease from 3,291.38 million tons in 2024 to 2,947.57 million tons in 2030. The reduction of carbon dioxide emissions shows that green innovations, technologies, and investments will contribute to the sustainability of economic development and reorientation to a carbon-neutral model. This should be accompanied by a change in state policy, the search for additional sources of funding for "green" technologies through their transfer and cross-sectoral integration.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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