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Bioeconomy of Ukraine: Efficiency and Potential for Development Based on SEE-Management Methodology

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The study of the efficiency and potential for developing the bioeconomy in Ukraine is highly relevant in the conditions of modern economic and environmental challenges. The current economic situation, complicated by military aggression, requires transformational changes aimed at sustainable development and decarbonization of the economy. Bioeconomic transformation is important in achieving the country's sustainable development goals and climate neutrality. The study aims to evaluate the efficiency of bioeconomic industries and determine their resource potential for developing management strategies for the bioeconomic transformation of socio-economic systems in the future. The methodology of SEE-analysis (scale, effectiveness, and efficiency analysis), which allows the evaluation of the efficiency and effectiveness of complex systems, is used in the study. Statistical indicators of turnover, production costs, and value-added of the bioeconomic sectors of Ukraine's economy are used for the analysis. The study results show that Ukraine's bioeconomic industry has a significant potential for development, but the main growth is due to quantitative, not qualitative, indicators. The largest share of value-added is generated by agriculture and food production. At the same time, there is a need to increase the efficiency of the resources used with innovative technologies. The study emphasizes the importance of developing the bioeconomy to reduce dependence on fossil resources and improve the ecological situation in the country because the bioeconomic transformation could contribute to strengthening the economy of Ukraine and its integration into the European economic space. The obtained research results can be used to develop policies and strategies for managing bioeconomic transformation in Ukraine. The proposed methodology can be used to evaluate the effectiveness of other socioeconomic systems at different levels, such as the regional, industrial, or enterprise levels.

Keywords: bioeconomic transformation, Ukraine, potential, SEE-analysis, SEE-management.

Introduction

Despite the catastrophic economic situation in Ukraine, primarily related to military aggression, the country's leaders recognize the need to remain focused on green transformation and recovery by European values. Before the full-scale invasion, Ukraine successfully implemented the measures necessary to start the green transformation. The first was the preparation of the Nationally Determined Contribution of Ukraine to the Paris Agreement. This is the main process for understanding the development of the economy. The results of modelling scenarios for the development of climate policy in Ukraine make it possible to propose Ukraine's contribution to greenhouse gas emissions at a level ranging from 27% to 46% compared with 1990 (UGP, 2020). According to the analytical report, to confirm that Ukraine shares the climate policy goals of the European Union (EU), in August 2020, the government of Ukraine notified the EU governing bodies about Ukraine's participation in the European Green Deal. The key goal of the state's climate policy is to reduce greenhouse gas emissions by 65% by 2030, and it is planned to achieve climate neutrality by 2060 at the latest (Ivanyuta and Yakushenko, 2022). This goal is also declared in the recently presented National Energy and Climate Plan (NECP) (UGP, 2024).

Because bioeconomic transformation is a well-recognized tool for achieving EU goals related to mitigating the consequences of climate change and reducing dependence on fossil resources (Fehrenback et al., 2017), some scholars (Banerjee et al., 2018) emphasize the significant potential of the bioeconomy in solving the climate problems caused by the use of fossil fuels for the production of thermal energy, electricity, and fuel. In addition, other components of bioeconomic transformation, such as the development of bioenergy and the introduction of sustainable innovation value-added chains, have been recognized (Honegger and Reiner, 2018) as effective for achieving the ambitious climate goals of the Paris Agreement.

Even though in recent decades, a number of studies have been carried out proving the negative impact of the intensive use of fossil fuels on the environment and climate change, as well as increasing public awareness and concern about the unsustainable nature of the current economic dependence on fossil fuels (Pfau et al., 2014; Vostriakova, 2024), sustainable bioeconomic transformation processes are still quite slow and difficult to implement. The Special Report "Global Warming of 1.5°C" (IPCC, 2018) states that CO_2 emissions from fossil fuel usage account for 89% of all CO_2 emissions. In the last few years, the gradual progress in this direction around the world has been accelerated by shocks such as the COVID-19 pandemic and the exacerbation of international conflicts, including the full-scale invasion of Russia into Ukraine, which actualized the problems of achieving the goals of sustainable development, carbon neutrality, and energy independence (Naidoo and Fisher, 2020; OECD, 2023).

At the beginning of 2024, the Government of Ukraine presented the National Energy and Climate Plan for discussion. "The preparation of NECP is an obligation of Ukraine within the framework of the Treaty on the Establishment of the Energy Community in accordance with the requirements of EU Regulation 2018/1999 and the relevant methodological recommendations of the European Commission. In addition, the development and approval of NECP is a condition for the distribution of EU financial assistance within the framework of the future special instrument Ukraine Facility" (UGP, 2024).

Within the framework of the NECP adopted (UGP, 2024), Ukraine has defined key goals until 2030 both at the national and regional levels (within the Energy Community). In particular, a number of intended goals directly relate to the process of bioeconomic transformation, namely:

1 Reduction of greenhouse gas emissions by 65% compared with the level of 1990;
2 Climate neutrality of the energy sector by 2050;
3 The share of renewable energy sources in the structure of gross final energy consumption – at least 27%;
4 Primary energy consumption – no more than 72 224 thousand tonnes of oil equivalent (toe); final energy consumption – 42 168 thousand toe;
5 Development and financing of innovation and research in the sector of clean technologies, renewable energy and low-carbon production;
6 Increasing competitiveness.

It becomes obvious that today, based on the Ukrainian realities, the government sees the decarbonization of the national economy as the main task in environmental policy. In its essence, the concept of bioeconomic transformation involves the transition to renewable energy sources due to the sustainable use of biomass.

Accordingly, the main, clearly defined path of bioeconomic transformation at the first stage of its socio-economic development involves the use of the first two paths of bioeconomic transformation: (1) replacement of fossil fuels with bio-materials and bio-resources; and (2) increasing efficiency in the primary sector of the economy through biotechnology implementation.

A number of studies (Stark et al., 2022; Losacker et al., 2023) have also emphasized that carbon capture or new transport mobility strategies and the introduction of sustainable consumption strategies can help reduce greenhouse gas emissions. However, a more profound, transformational transition to sustainability requires the development of comprehensive and consistent bioeconomic strategies, including the widespread implementation of innovative biotechnologies, which is a higher level of the bioeconomic transformation path, often less accessible to low and middle-income countries.

To date, several methodological approaches and indicators have been developed to assess and analyze sustainable bioeconomy (EU, 2015; Fritsche and Iriarte, 2014). However, the developed methods are mostly focused on quantitative rather than qualitative indicators, which leads to an inadequate assessment of bioeconomic processes. However, the research technology of bioeconomic processes should be improved due to the search for methodological tools and economic-mathematical models that allow taking into account the relevant relationships between the parameters of bioeconomic systems at different levels. The indicators of the effectiveness of their functioning (from the point of view of their efficiency obtaining final results, with the possibility of further evaluation and analysis of the obtained results and possible further improvement) are still relevant.

Our research aims to assess the scale, effectiveness, and efficiency of Ukraine's bioeconomic industries functioning and potential development and propose relevant management strategies for future bioeconomic transformation of complex socio-economic systems.

Methods

Our study is based on the theoretical-methodological approach – SEE-analysis methodology (SEE defined as scale, effectiveness, efficiency) – developed by Burennikova and Yarmolenko (2017). The methodology allowed us to determine the vectors of the bioeconomic transformation of socio-economic systems. Following Burennikova and Yarmolenko (2017), SEE-analysis of the functioning processes of complex systems implies the analysis of the effectiveness of these processes and corresponding indicators of scale, effectiveness, and efficiency of the subprocesses.

The suggested methodology reflects a system of categorical concepts (scale, effectiveness, efficiency) used in the cognitive processes. The SEE-management approach has been used in practice to determine the effectiveness of processes for over 20 years. According to this methodology (Burennikova and Yarmolenko, 2017), SEE-analysis is carried out within the paradigm "cognitive knowledge – measurement – evaluation – management" and is aimed at calculating and assessing the indicators of the performance components using the potential of the socio-economic system. The methodology measures and evaluates economic processes using indicators: scale (K), effectiveness (R), and efficiency (E). The letters were randomly chosen for technical reasons and cannot be changed due to copyright regulations (Burennikova and Yaromolenko, 2017). Wu and Wu (2012) highlighted that "using indicators helps to build a more detailed system of indexes that characterize their quantitative and qualitative dimensions and evaluate the proposed indicators in dynamics. To reduce the number of indicators or reflect a system's integrative characteristics, indicators are often combined through mathematical manipulations to produce indexes. In other words, an index is an aggregate of two or more indicators. The distinction between an indicator and an index can be difficult and unnecessary because both frequently aggregate variables themselves, meaning their difference is merely a matter of the degree of aggregation" (Wu and Wu, 2012, p. 70). To achieve the aim of the study, we used the models of the constituent parts of the bioeconomic transformation process effectiveness and those listed below as indicators of the process performance with a more detailed system of indexes. According to Burennikova and Yarmolenko (2017), these models are based on the premise that the outcome of any bioeconomic process includes production costs, the estimated consumer benefits as added value, and the overall scope of the processes.

The indicators of the bioeconomic transformation process performance are the following:

$$G = (V - Z) \quad (1)$$

where V is an indicator of the total product of the process – the turnover of products (goods, services) of enterprises by types of bioeconomic activity for 2016–2020, UAH (Ukrainian hryvnia), million; Z is an indicator of its product as costs – production costs of goods (services) of the enterprises by types of bioeconomic activity for 2016–2020, UAH, million; G is an indicator of the product as an added value (benefit) of the process.

$$E = V/Z \tag{2}$$

where E is a process efficiency indicator as the ratio of the indicators of the total product V and the product as costs Z (a qualitative component of the process performance).

$$K = (G + Z * G/V) \tag{3}$$

where K is an indicator of the product scale of the process (a quantitative component of the process performance indicator).

$$R = K \cdot E = K * V/Z = G * V (1 + V/Z) \tag{4}$$

where R is an indicator of process effectiveness, which is determined by multiplying the indicator of the product scale of the process (K) by the indicator of its efficiency (E) (Burennikova and Yarmolenko, 2017; Polishchuk and Yarmolenko, 2014).

The category of any process performance (bioeconomic transformation as a set of processes) according to its final consequences (results) requires its simultaneous consideration (for evaluating the process of bioeconomic transformation) both from the quantitative side, in the form of characteristics of the large-scale product of the process, and from the qualitative side, taking into account efficiency of the process.

Structurally interconnected indicators of effectiveness and efficiency of bioeconomic transformation processes form a corresponding system, which contains quantitative and qualitative indicators, which, in turn, also contain quantitative and qualitative components (*Table 1*).

Table 1. *The architecture of interconnected models for calculating the components of the effectiveness/efficiency of bioeconomy processes as a complex dynamic socio-economic system*

Title	Marking	Models for calculation	
I. General indicators			
1. Total products of bioeconomic processes (turnover of products (goods, services) of enterprises by types of bioeconomic activity)	V_i		
2. Expenses of bioeconomic processes (production costs of products (goods, services) of enterprises by types of bioeconomic activity)	Z_i		
3. Value-added of bioeconomy processes	G_i	$G_i = V_i - Z_i$	(5)
II. Effectiveness indicators R			
1. Effectiveness of bioeconomy processes	R_i	$R_i = K_i * E_i$	(6)
2. Effectiveness of bioeconomy processes index	J_{Ri}	$J_{Ri} = R_i / R_{i-1}$	(7)
III. Scale indicators K (quantitative component performance)			
1. Scale of the (final products) bioeconomic processes	K_i	$K_i = G_i + Z_i * G_i/V_i$	(8)
2. Needed products for bioeconomic processes	K_{Gi}	$K_{Gi} = K_i * G_i/V_i$	(9)
3. Added products bioeconomy processes	K_{Zi}	$K_{Zi} = K_i - KG_i$	(10)
4. Index of bioeconomy processes scale	J_{Ki}	$J_{Ki} = K_i / K_{i-1}$	(11)
IV. Efficiency indicators E (quality component performance)			
1. Efficiency bioeconomy processes	E_i	$E_i = V_i / Z_i$	(8)
2. Quantitative component bioeconomy processes efficiency	E_{1i}	$E_{1i} = E_i - 1$	(9)
3. Bioeconomy processes efficiency index	J_{Ei}	$J_{Ei} = E_i / E_{i-1}$	(10)
4. Qualities of bioeconomy processes	E_{2i}	$E_{2i} = V_i / G_i$	(11)
5. Quality of bioeconomy processes index	J_{E2i}	$J_E = E_{2i} / E_{2(i-1)}$	(12)
6. Quantitative component of bioeconomy processes efficiency index	J_{E1i}	$J_E = E_{1i} / E_{2i}$	(13)

*Source: adopted based on Yarmolenko et al. (2021)

Following our research objective, we analyzed the country's bioeconomic transformation process, considering the defined limits of the bioeconomy in the structure of the country's national economy. The industries defined as bioeconomic are the following

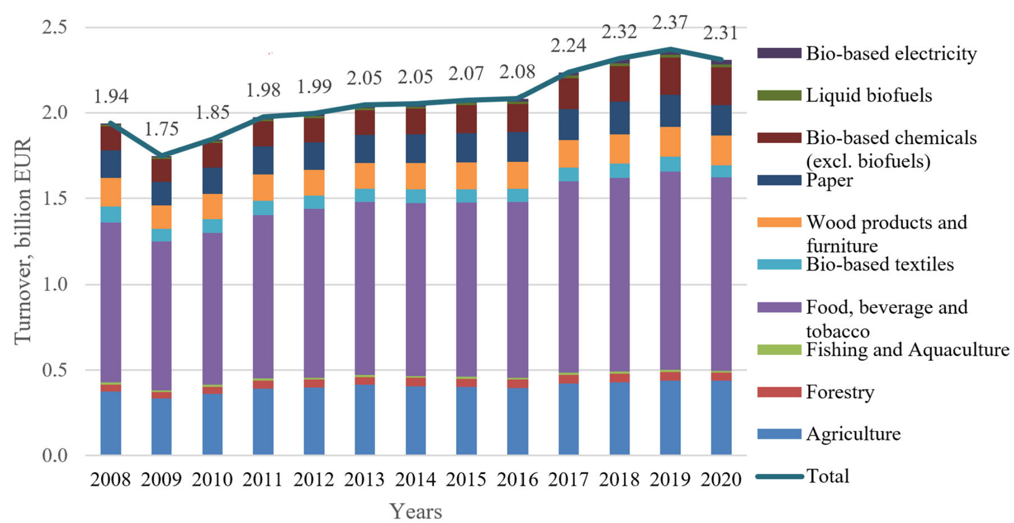
- Agriculture, hunting, and related services (NACE A.1);
- Forestry, logging, and other forestry activities (NACE A.2);
- Fish farming (NACE B.5);
- Production of food products, beverages, and tobacco products (NACE DA);
- Textile production, production of clothes, leather, leather products and other materials (NACE DB);
- Production of wood products, paper, and printing activities (NACE DD, DE);
- Production of furniture (NACE 310);
- Construction of buildings (NACE 41);
- Production of chemicals and chemical products (part of biochemicals) (NACE 2014);
- Collection, processing, and disposal of waste; recovery of materials (NACE 38).

Results and Discussion

The current economic limits of the bioeconomy depend on the bioeconomic areas included in its composition. The assessment of the EU bioeconomy contribution showed that its share was about one-tenth of the EU economy (EU-27) during 2012–2017 (Ronzon et al., 2022) and showed a gradual increase. The turnover dynamics of EU-27 bioeconomy sectors for 2008–2020 are shown in *Fig. 1*.

Today, bioeconomy is one of the most important components of the EU economy. The data shown in *Fig. 1* indicate that the turnover of the EU bioeconomy in 2020 reached approximately €2.31 billion.

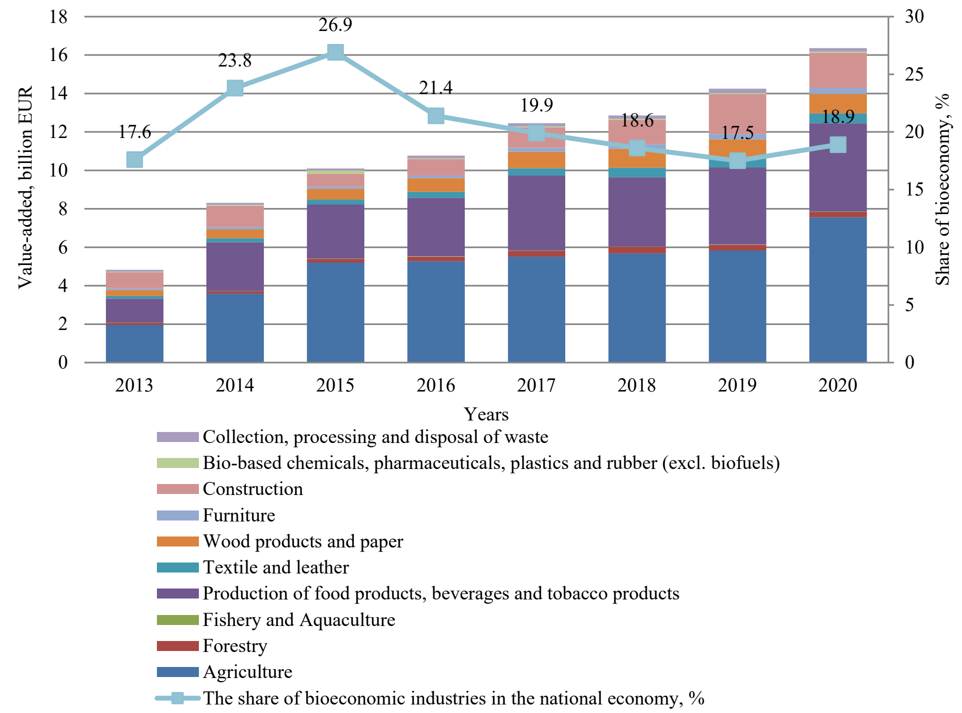
Fig. 1. *Dynamics of EU-27 bioeconomy sectors turnover, 2008–2020, billion EUR**



*Source: formed according to data of the European Commission. Data-Modeling platform of resource economics (n.d.)

The main sectors of the EU bioeconomy are defined and approved in the relevant Strategy for the Development of the EU Bioeconomy, which in particular include agriculture, forestry and water management, chemical, pharmaceutical, cellulose sectors, wood, food, and paper industries, bioenergy and biofuels. Based on the defined list, it is possible to estimate the bioeconomic potential of Ukraine based on the data from the State Statistics Service of Ukraine. The dynamics of the value-added creation by the main branches of the national economy of Ukraine (*Fig. 2*) related to the bioeconomy sector in 2013–2020 (except bioenergy) showed almost triple growth.

Fig. 2. *Growth dynamics of the bioeconomic potential (value-added) of Ukraine in 2013–2020, (billion EUR)**



*Source: calculated based on the data of the State Statistics Service of Ukraine (n.d.)

As can be seen from *Fig. 2*, in 2014 and 2015, the share of the bioeconomic sector increased sharply, not due to the increase of own capacities, but due to the reduction of the value-added from the heavy industry sector of the national economy due to the annexation of the industrial part of Ukraine – Donbas in 2014. In 2020, Ukraine's bioeconomic sector share reached almost 19%. For a more detailed analysis of the potential contribution of the bioeconomy to the national economy of Ukraine, it is necessary to evaluate the leading indicators characterizing the real contribution of the bioeconomy sectors to the national economy: the value-added created and the number of jobs by types of economic activity belonging to the bioeconomy sector (*Table 2*).

According to the State Statistics Service of Ukraine, the value-added potentially generated in the bioeconomic sector of Ukraine as of the end of 2020 was 17.23 billion EUR, while in 2013, it was only 5.32 billion EUR (see *Fig. 2*). The largest share of the value-added of bioeconomic potential of Ukraine was generated by agriculture (43.9%) and the food, beverage and tobacco production sector, which accounts for more than 26% of the bioeconomic value-added, followed by the construction sector, paper, textile and chemical production (from 3% to 10%). A total of 1.32 million employees (about 17%) were employed in the bioeconomy sector of Ukraine, while more than 66% of people were employed in the bioeconomy agricultural sector and food production (see *Table 2*). In general, the growth of the bioeconomic sector of Ukraine showed positive dynamics and, what is most important for Ukraine in the light of the current external threats in the conditions of the aggression of a neighboring state, was more resistant to the conditions of crisis phenomena (2014–2015), showing a slight but still growth (see *Fig. 2*), implying that it has the ability to adapt.

Since the bioeconomy concept has been reoriented to use not only primary sources of biomass (such as wood, crops, and waste) but also biomass from recycled waste, such products have formed their niche in energy production. It is also important that the bioeconomy sector consumes biomass not only from the fields of plant and animal husbandry (including residues after harvesting) but also from forestry and water and waste management during production and consumption.

Table 2. *The potential contribution of the bioeconomic sector of Ukraine to the national economy in 2020**

Branches of the national economy	Value-added by types of economic activities			Employees by type of economic activities		
	Billion EUR	Share in %		Persons	Share in %	
		BE	NE		BE	NE
Agriculture	7.56	43.90	8.28	462 976	35.00	6.27
Forestry	0.28	1.61	0.30	56 004	4.23	0.75
Fishery and Aquaculture	0.02	0.09	0.02	4802	0.36	0.06
Food, beverages and tobacco	4.59	26.65	5.02	354 380	26.79	4.80
Textile and leather:	0.51	2.98	0.56	18 730	1.41	0.25
incl. leather products and other materials	0.11	0.64	0.12	21 402	1.61	0.29
Wood products and paper	1.01	5.87	1.10	105 862	8.00	1.43
Production of furniture	0.30	1.75	0.33	46 771	3.53	0.63
Construction of buildings	1.83	10.62	2.01	151 876	11.48	2.05
Production of chemicals:	0.75	4.37	0.82	63 557	4.80	0.86
incl. basic organic chemicals	0.07	0.40	0.07	8503	0.64	0.12
Processing of waste	0.18	1.06	0.20	27 642	2.09	0.37
Total bioeconomic sector	17.23	-	18.86	1 322 505	-	17.92
Total national economy	91.30	-	-	7 379 539	-	-

BE = Bioeconomy

NE = National economy

*Source: author's elaboration.

Solid waste (SW) becomes a resource, adding value in this context. This type of waste has been dismissed from the field of economic theory and business as not very useful. Today, solid waste is considered as a potential source of renewable resources and energy, which meets the growing needs in the context of achieving the goals of sustainable development. In particular, SW is waste generated by commercial and domestic sources that are collected and processed, incinerated, or disposed of in SW landfills. However, a circular approach involves the implementation of principles of zero-waste production. Usually, it includes innovation along the entire value chain, not just before the end of the product's life. A closed production cycle and the concept of circularity in the economy are becoming strategic goals for many economies. In the European Union, the "Europe without waste" program, the "EU Action Plan for the Development of the Circular Economy" and many other measures have been taken to implement the principles of circularity in the economy of the Member States. Circularity in economic systems should be focused on keeping value-added products as long as possible, ensuring their highest utility and zero waste, which is important to verify with the help of appropriate performance indicators (Yarmolenko and Burennikova, 2019). Accordingly, circularity must be part of the modern, broader bioeconomy concept. The transition to a circular bioeconomy is recognized (Maksymiv et al., 2024) as the most effective and efficient mechanism for the development of sustainable, low-carbon and resource-efficient socio-economic systems, in which measures are actively implemented to preserve products, materials, and resources in the economy as long as possible, and also create conditions for minimizing waste generation.

The introduction and implementation of the declared directions of bioeconomic transformation fully correspond to the main priorities of the sustainable development of Ukraine and require the modernization of the national economy model, by the concept of anticipatory development, which could help catch up and reduce Ukraine's lag behind the developed countries of the world (Yagelska, 2015). The declared concept is based on the energy theory of development, the so-called "energy approach", according to which accelerated development becomes possible due to the activation of the country's internal energy. We support the conclusions of Yagelska (2015) that the conceptual idea of anticipatory national economic development is based on the basic aspects of the updated development paradigm, which rejects static economic equilibrium and inertial market self-organization and connects the development process with the energy power (Yahelska, 2016). As the basis of the theoretical and methodological level of the concept of anticipatory development, the author lays down the ontology of anticipatory national economic development, the result of the search for its key determinants (among which the temporal factor and the effectiveness factor were identified), as well as the provisions of the energy approach, which reveal the resource and praxeological aspects of anticipatory national economic development, the impetus for which, in our opinion, can be the bioeconomic transformation of the branches of the national economy based on sustainability and circularity.

In her work, Yagelska (2015) noted that "the methodological specificity of the energy approach is that the proposed approach involves the study of the development of the economic system from the point of view of evaluating its economic energy, which is the driver of economic development, and focuses on the search for impulses capable of provoking an impulse of this energy, which must bring the system out of a certain stable condition. This actualizes the study of resonance, which can lead to positive economic development and maintenance of dynamic balance, emphasizing the importance of resonance management. Resonance management of national economic development is understood as the activity of the state to ensure coordination in space and time of the characteristics of external disturbances and internal properties of the economic system to sharply increase the amplitude of its internal oscillations, capable of forming the energy impulse of its transition from one condition of dynamic equilibrium to another, qualitatively new, according to account of the synergistic effect of the behavior of various owners of economic energy as a result of the influence of the government".

Based on the above-mentioned theoretical grounds, we assume that Ukraine's rich natural resource potential and the declared European integration policy of the country's sustainable development could potentially drive the country's economic transformation towards the bioeconomy. Developing a bioeconomic transformation strategy based on the principles of sustainable development must serve as an impetus for further changes in the system, which requires developing an effective public administration system and assessing the effectiveness and efficiency of transformation processes.

In connection with this, there was a need to develop and improve the methodology for measuring the performance (in particular, efficiency and effectiveness) of the bioeconomic system processes based on Burennikova and Yarmolenko's (2017) models. Based on the theoretical justification of the concept of anticipatory economic development and the methodological apparatus by Burennikova and Yarmolenko, we proposed conducting a SEE-analysis of Ukraine's bioeconomic system's potential functioning and development.

Table 3 shows the average annual socio-economic data of bioeconomic industries for 2016–2020 regarding primary income. According to the presented data, under the methodology discussed above, we evaluated the effectiveness of the process of primary income generation in the bioeconomic system of Ukraine, both separately and in comparison, with the traditional economy at the national level.

Based on the determined statistical indicators of production turnover (V) and value-added G in the bioeconomic and general economic sectors of Ukraine for 2016–2020 (on average per year per employee in million EUR), we calculated scale (K), effectiveness (R), and efficiency (E) with corresponding indexes, using the following above formulas according to Burennikova and Yarmolenko's methodology (*Table 4*).

From the data in *Table 4* and *Fig. 3*, it can be seen that, at the national level, there is a tendency to decrease the effectiveness of obtaining primary income of enterprises by types of management, which is reflected in the gross value-added, accordingly. Accordingly, we observe negative fluctuations in the effectiveness indicator during the study period at –18%, –4%, 12%, –8% respectively, due to the relative decrease in the scale of the process by 20%, 0%, –1%, –5% as well as corresponding fluctuations in the process efficiency.

Table 3. *Dynamics of studied socio-economic data in the national economic system of Ukraine and its bioeconomic component for 2016–2020, million EUR*

	National economy				
	2016	2017	2018	2019	2020
1. Turnover	134 882.6	162 696.1	196 043.8	196 919.1	189 191.0
2. Production costs	95 831.35	117 702.4	148 535.3	146 103.4	145 018.9
3. Number of employed workers	201 428.5	194 087.5	20 7647.2	200 235.5	185 061.2
4. Value-added	59 120.5	70 100.33	80 508.03	85 759.24	83 815.12
	Bioeconomy				
1. Turnover	41 374.64	47 792.45	56 266.25	54 277.39	53 965.89
2. Production costs	32.25	37.69	47.30	44.46	44.09
3. Number of employed workers	50 147.67	48 296.46	50 828.43	45 446.69	40 586.92
4. Value-added	19 384.86	20 783.86	22 392.1	21 846.44	24 112.28

*Source: author's elaboration.

Table 4. *Dynamics of the gross value-added generation indicators at the level of enterprises of the Ukraine's national economy for 2016–2020*

Year	V	Z	G	J_G	$1 + D_z$	
2016	0.66963	0.475759	0.193871	–	1.71048	
2017	0.838261	0.60644	0.231821	1.195749	1.72345	
2018	0.94412	0.715326	0.228794	0.986941	1.757664	
2019	0.983438	0.729658	0.25378	1.109206	1.741946	
2020	1.022316	0.783627	0.238689	0.940535	1.766521	
Year	J_{1+Dz}	K	J_K	E	J_E	
2016	–	0.331613	-	1.407499	–	
2017	1.007582	0.399533	1.204816	1.382266	0.982072	
2018	1.019852	0.402143	1.006534	1.319846	0.954842	
2019	0.991058	0.442071	1.099287	1.347807	1.021185	
2020	1.014108	0.421649	0.953804	1.304595	0.967939	
Year	R	J_R	$J_{G/Z}$	$J_{V/G}$	J_V	J_Z
2016	0.466745	–	–	–	–	–
2017	0.552261	1.183217	0.938078	1.046898	1.251828	1.27468
2018	0.530767	0.961082	0.836711	1.141185	1.126283	1.179549
2019	0.595826	1.122575	1.087419	0.939091	1.041645	1.020036
2020	0.550081	0.923224	0.875759	1.105257	1.039533	1.073965

*Source: author's elaboration based on methodology and indexes explained in *Table 1*.

J_R – effectiveness
J_K – scale
J_E – efficiency
J_G – gross income
$J_{(1+Dz)}$ – shares of product consumption
$J_{(G/Z)}$ – the quantitative component of efficiency
$J_{(V/G)}$ – a qualitative component of efficiency
J_V – the volume of produced products
J_Z – production costs

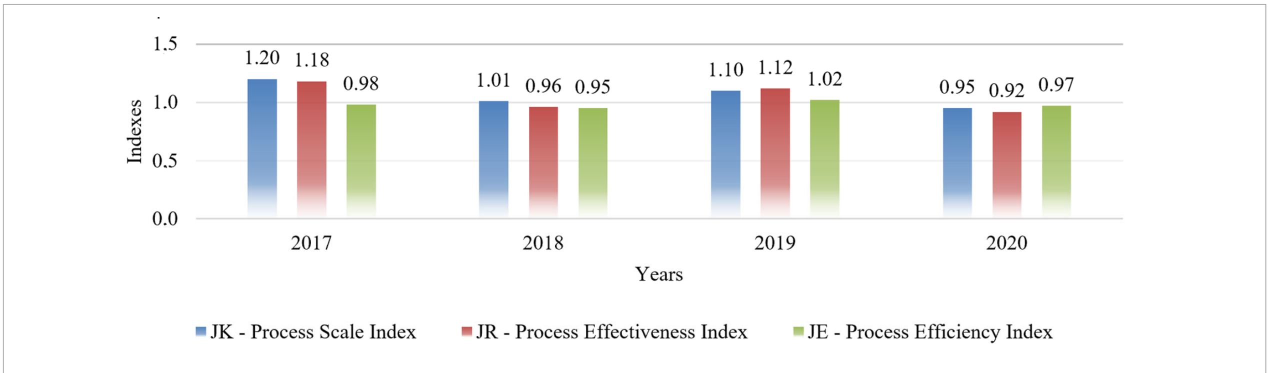
It should be noted that the downward trend is observed against the background of available reserves for the growth of the qualitative component in 2019 (index $J_{V/G}$) and the quantitative component in 2017, 2018, and 2020 (index $J_{G/Z}$). The relative decrease in the scale of the process occurred due to changes in production costs, namely due to their growth in the corresponding periods.

According to the data in *Table 5* and *Fig. 4,* it can be concluded that in 2016–2020 in Ukraine, regardless of the state of affairs at the national level of the economy, enterprises of the bioeconomy sector demonstrated a relative increase in the effectiveness of the process of forming value-added of 18%, 5%, 11%, 12% due to the relative increase in the scale of the process, (J_K index), respectively by 20%, 12%, 8%, 11% with a relatively insignificant relative change in its efficiency.

It should be emphasized that the relative increase in the scale of the process in the bioeconomic sector occurred mainly due to the relative increase in value-added (20%, 12%, 8%, and 11%, respectively) at a practically constant level of production costs (index J_{1+Dz}). In addition, it is necessary to note the presence of reserves for increasing the effectiveness of income generation in the bioeconomic sector due to the quantitative component of the process efficiency (index $J_{G/Z}$) in 2017 and 2018, and the qualitative component (index $J_{V/G}$) in 2019–2020.

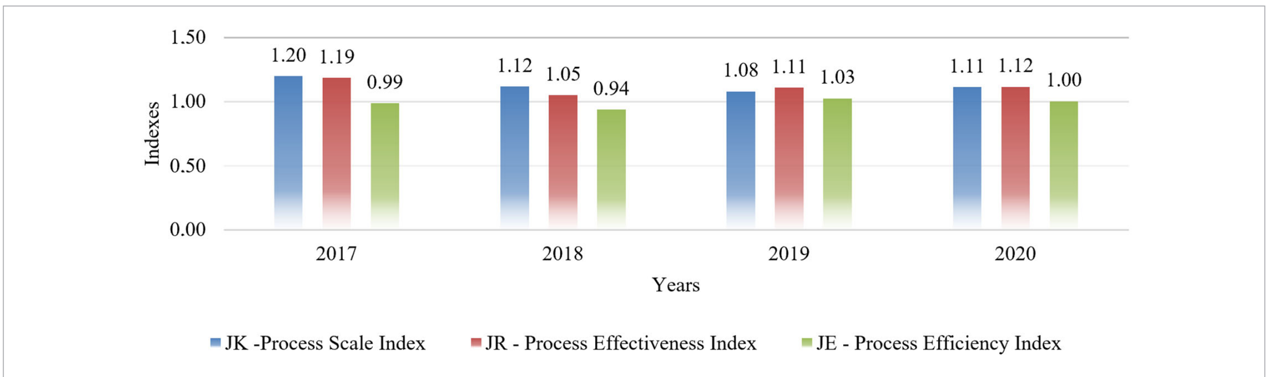
The comparison of the studied indicators and corresponding indexes allowed us to evaluate the economic activity of enterprises by types of economic activity of the general (traditional) national industry scale and the bioeconomic sector in terms of enterprise income generation. *Fig. 5* presents a visual representation of the dynamics of indexes of the value-added generation process.

Fig. 3. *Indexes of the gross value-added generation process by enterprises at the level of the national economy in 2017–2020*



*Source: author's elaboration.

Fig. 4. *Indexes of the gross value-added generation process by enterprises of the bioeconomy sector in 2017–2020*



*Source: author's elaboration.

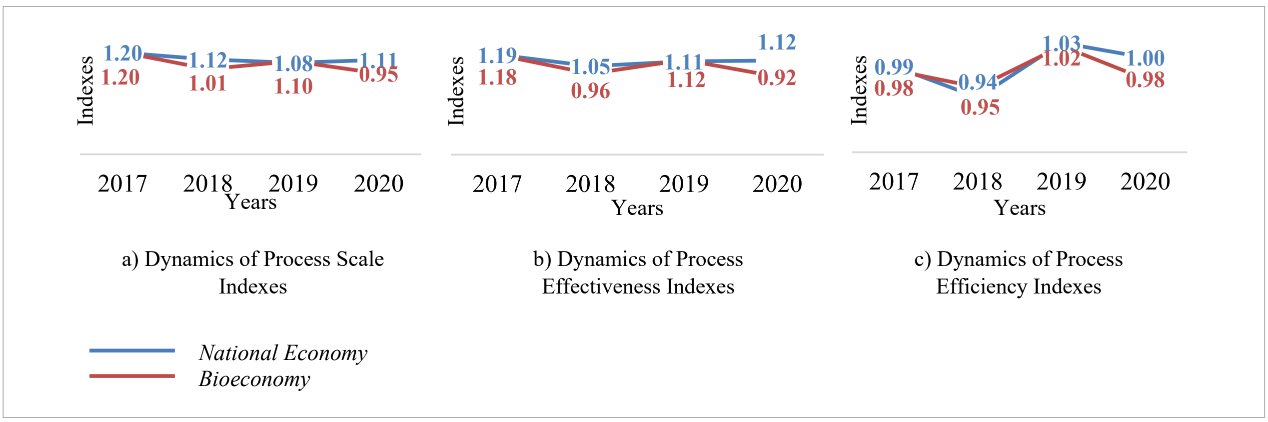
Table 5. *Dynamics of the gross value-added generation indicators at the level of enterprises of the bioeconomic sector of Ukraine for 2016–2020*

Year	V	Z	G	J_G	$1 + D_z$	
2016	0.825056	0.000643	0.824413	–	1.00078	
2017	0.989564	0.000781	0.988784	1.19938	1.000789	
2018	1.106984	0.000931	1.106053	1.118599	1.000841	
2019	1.194309	0.000978	1.193331	1.078909	1.000819	
2020	1.329637	0.001087	1.328551	1.113313	1.000817	
Year	J_{1+Dz}	K	J_K	E	J_E	
2016	–	0.825055	–	1282,802	–	
2017	1.000009	0.989564	1.199391	1267,816	0.988318	
2018	1.000052	1.106983	1.118658	1189.43	0.938173	
2019	0.999978	1.194308	1.078886	1220,714	1.026302	
2020	0.999998	1.329637	1.113311	1223,727	1.002468	
Year	R	J_R	$J_{G/Z}$	$J_{V/G}$	J_V	J_Z
2016	1058,383	–	–	–	–	–
2017	1254,585	1.185379	0.988309	1.000009	1.199391	1.213568
2018	1316,679	1.049494	0.938124	1.000052	1.118658	1.192379
2019	1457,909	1.107262	1.026324	0.999978	1.078886	1.051237
2020	1627,113	1.116059	1.00247	0.999998	1.113311	1.11057

*Source: author's elaboration based on methodology and indexes explained in *Table 1*.

J_R – effectiveness
J_K – scales
J_E – efficiency
J_G – gross income
$J_{(1+Dz)}$ – shares of product consumption
$J_{(G/Z)}$ – the quantitative component of efficiency
$J_{(V/G)}$ – a qualitative component of efficiency
J_V – the volume of produced products
J_Z – production costs

Fig. 5. *Comparative dynamics of gross income generation process indexes in bioeconomy and traditional economy*

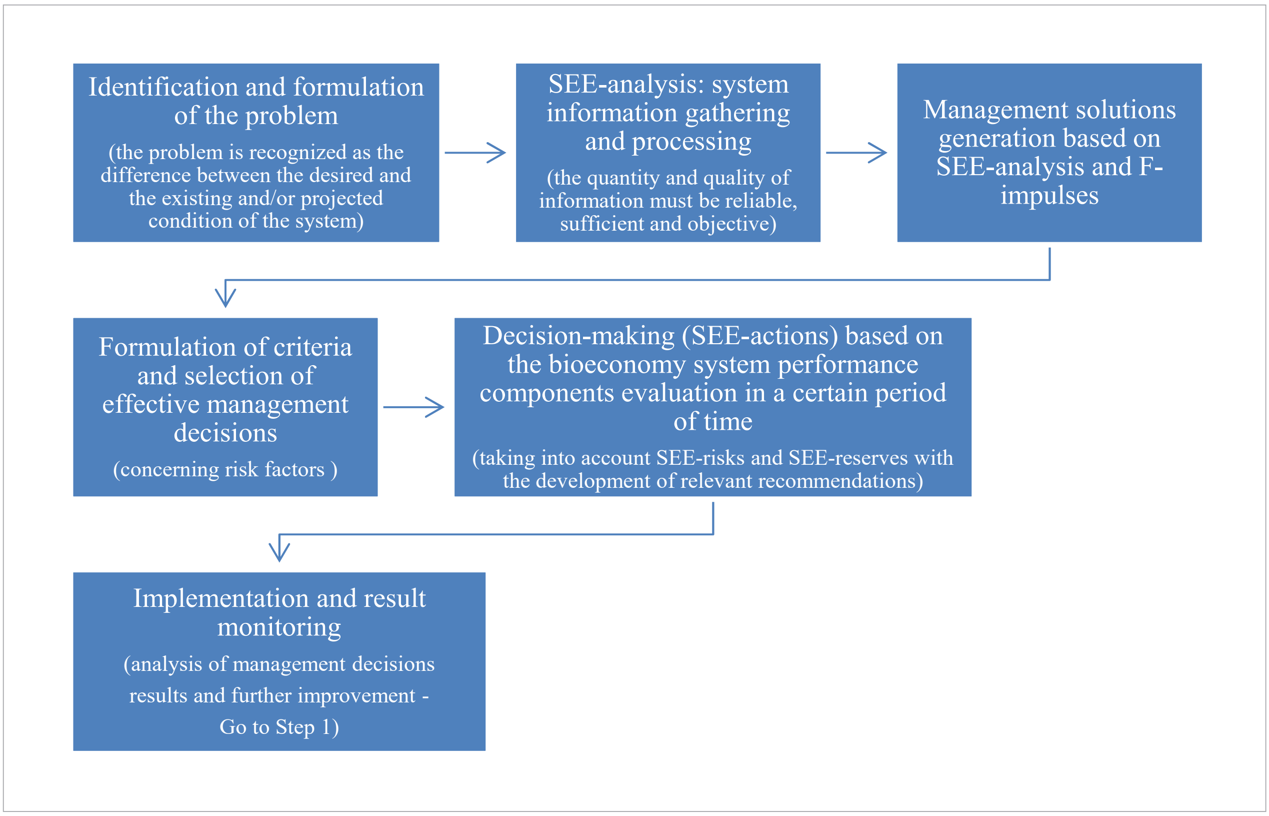


*Source: author's elaboration.

According to the obtained data, the scale, effectiveness, and efficiency indexes were higher in the bioeconomic sector in the studied period. In addition, the results demonstrated in *Tables 2* and *3* indicate the presence of qualitative and quantitative reserves in the bioeconomy sector to increase the efficiency and effectiveness of economic entities' value-added generation process.

In order to further develop a management strategy for bioeconomic transformation after the stage of a detailed assessment of bioeconomy processes performance and determination of the existence of certain reserves for its improvement, it is essential to determine the main drivers and risks of this process, which, in our opinion, can be implemented with the help of SEE-management tools and algorithms (Yarmolenko et al., 2021). According to the author's vision, we improved the conceptual mechanism of SEE-management of complex systems (*Fig. 6*), which as a bioeconomic system should take into account the peculiarities of the functioning of these systems in the conditions of a changing external environment, as well as a set of goals, tasks, functions, principles, methods, means, techniques, factors, technologies, resources (including information), types, results, requiring appropriate management actions in response to their change. Considering that the assessment of factors, drivers, risks, and goals of Ukraine's bioeconomic system is not the task of this study, they are not presented in detail here, but can be found in our previous research (Vostriakova, 2024) and can be used in the decision-making process. The indicators of the bioeconomic system components performance, obtained above (*Table 5*), are part of SEE-management of a complex systems mechanism, which involves the use of F-impulses as indicators of the consequences direction under the processes of the bioeconomic system, which were used to characterize management SEE-actions based on the SEE-analysis results of the performance of bioeconomic transformation process components.

Fig. 6. *Adaptive algorithm of SEE-management of bioeconomic transformation of socio-economic systems*



*Source: author's elaboration.

To ensure the decision-making process according to this algorithm, the following components are necessary: indicators of SEE-analysis results, including F-impulses (factors); toolkit which would help to implement the adopted decisions; specialists and institutions (which identify the state of the system and make and implement the appropriate management decision).

As an example of applying the research methodology of SEE-management, we took the indicators and related indexes of the value-added generating process at the level of enterprises in the bioeconomic sector of Ukraine as a system. The data in *Table 5* show the growth rate of value-adding generating indexes of the bioeconomic sector of Ukraine in 2020 (in %, presented in *Table 6*).

The value of ΔJ_R indexes, ΔJ_K, ΔJ_E, ΔJ_G, $\Delta J_{(1+Dz)}$, $\Delta J_{G/Z}$, $\Delta J_{V/G}$, ΔJ_V, ΔJ_Z from *Table 5* demonstrates the degree of influence of relevant factors on the value-added generating process of the bioeconomic sector of Ukraine. These investigated factors of the process were, respectively, the effectiveness of the process (with the indicator *R*); the scale of the process (with indicator *K*); process efficiency (with *E* indicator); value-added (with indicator *G*); the share of product consumption (with an indicator of 1 + *Dz*); the quantitative component of process efficiency (with *G/Z* indicator); the qualitative component of process efficiency (with the *V/G* indicator); net income (revenue) from the sale of products (goods, works, services) (with indicator *V*); material costs and depreciation (with *Z* indicator). The parameters of F-impulses, which defined existing reserves (*F* = *R*, *K*, *E*, *G*, 1 + *Z*/*V*, *G*/*Z*, *V*/*G*, *V*, *Z*), are defined as the growth rates of the specified indicators (*Table 6*).

F-impulses of the bioeconomic transformation process were taken as factors that form the products of this process *(F = R, K, E, G, 1+ Dz, G/Z, V/G, V, Z)*. These impulses can be both positive and negative. In *Table 5*, some F-impulses *(F = K, E, R, G, 1 + Dz, G/Z, V/G)* are equivalent to the corresponding F-impulses, that is, dependent on them. Only *V* and *Z* impulses are independent F-impulses.

The SEE-management matrix (see *Table 6*) based on the results of the SEE-analysis of the process (see *Table 5*), in our opinion, fully and completely demonstrates the F-impulses and their impact on the process under investigation, SEE-reserves, and SEE-risks, recommended SEE-actions. For example, from the data in *Table 6* (line 3), we can see that in the bioeconomy system of Ukraine in 2020, compared with 2019, there was a slight increase in the level of effectiveness of generating gross income process (ΔJ_R) by 0.9% mainly due to an increase in the level of

Table 6. *Matrix (map) of SEE-management based on the results of the SEE-analysis of the value-added generating process by bioeconomic sector enterprises in 2020*

Parameters of F-impulses (F = R, K, E, G, 1 + Z/V, G/Z, V/G, V, Z) as growth rates of indicators								
0.9	3.5	–2.3	3.4	0	–2.4	0	3.4	5.9
The influence of F-impulses on the process under investigation								
Positive	Positive	Negative	Positive	Neutral	Negative	Neutral	Positive	Positive
Identification of SEE-reserves and SEE-risks								
+	+	–	+	=	–	=	+	+
Recommended SEE-management actions								
Provide no less level	Provide no less level	Ensure growth	Provide no less level	Ensure growth	Ensure growth	Ensure growth	Provide no less level	Provide no less level

*Source: elaborated by the author based on Yarmolenko et al. (2021)

ΔJ_R – effectiveness

ΔJ_K – scale

ΔJ_E – efficiency

ΔJ_G – gross income

$\Delta J_{(1+Dz)}$ – shares of product consumption

$\Delta J_{(G/Z)}$ – the quantitative component of efficiency

$\Delta J_{(V/G)}$ – a qualitative component of efficiency

ΔJ_V – the volume of produced products

ΔJ_Z – production costs

scale (ΔJ_K) increased by 3.5%, because the efficiency of the process (ΔJ_E) decreased by 2.3%. Moreover, the increase in the level of the scale occurred with an increase in gross income (ΔJ_G) almost proportionally by 3.4% and zero influence of the share of product consumption (ΔJ_{1+Dz}). In turn, the decrease in the level of efficiency of the process was explained by the decrease in the level of its quantitative component ($\Delta J_{G/Z}$) by 2.4% with an unchanged level of the qualitative component ($\Delta J_{V/G}$) $\Delta J_{V/G} = 0$; at that time, the volume of produced products (ΔJ_V) increased by 3.4%, and the costs of production (ΔJ_Z) increased by 5.9% (line 3). As can be seen from the conducted analysis, in 2020, the effectiveness of the bioeconomic system maintained a tendency towards insignificant positive growth only due to quantitative factors, while the efficiency of processes remained low because the increase in turnover entailed an increase in the growth of costs (line 5). The factors of process efficiency, product consumption, and quantitative and qualitative components of efficiency can lead to SEE-risks and limit the effectiveness of the process of bioeconomic transformation; all others are related to SEE-reserves (line 7). It is recommended to ensure an increase in the influence of the shares of product consumption share and the qualitative and quantitative component of the efficiency of the value-added generation process of the bioeconomic sector, which is being studied. For all other remaining factors, at least the same level of influence should be ensured (line 9).

In this context, to increase the efficiency of processes in Ukraine's bioeconomy sectors, it is important to introduce innovative technologies (Richardson, 2012) and management methods (Hahn, 2018) into production processes using the principles of circular economy (Bezama, 2018) and cascade processing of biomass (De Besi and McCormick, 2015). Bioeconomic transformation opens new opportunities for increasing the efficiency of production processes by forming sustainable value chains, industrial symbiosis (Hildebrandt et al., 2018), and biomass valorization while reducing the negative impact on the environment and at the same time, ensuring the achievement of sustainable development goals. In addition, the bioeconomic approach creates opportunities for the formation of integration of industrial ecosystems, which, in addition to reducing production and transaction costs, make it possible to minimize waste generation by reprocessing them (Bezama, 2018), providing stimulating natural cycles of growth (assimilation) and remineralization following life cycle assessment approach.

Our research is limited by the fact that we analyzed the period from 2016 to 2020, which cannot fully reflect the current state of bioeconomic entities functioning in Ukraine, which is primarily due to the occupied part of the territory of Ukraine and closed access to information in the following years, since data from studied industries are strategic, and the information is confidential at the moment. However, given the fact that all indicators, under the methodology, were calculated in the dynamics for the 5 studied years, which took into account the first wave of deindustrialization of Ukraine caused by the first wave of occupation of Ukrainian territories, it can be stated that our study to a certain extent showed the main trends of bioeconomic potential and its development in Ukraine. This limitation could be overcome in future studies by considering the updated data after canceling restrictions on their coverage.

In addition, the study does address regional context and disparity in resources, infrastructure, or economic conditions that could affect the efficiency and potential for bioeconomic development, and detailed regional analysis could uncover specific challenges or opportunities unique to different areas of the country using the proposed methodology in further research. Since the considered method of using the performance components of the subprocesses of the complex systems functioning can be used to study the performance of any systems level (Yarmolenko et al., 2022), the proposed methodological approaches to managing the bioeconomic transformation of socio-economic systems can be used to study socio-economic systems of various levels at the micro-, meso- and macro-levels (subject to a special selection of indicators and indicators of individual processes occurring at these levels, which is associated with the peculiarities of the selection of units of measurement of process products). Future research in the field of SEE-analysis of bioeconomic potential in terms of efficiency, effectiveness, and scale of value-added processes in the bioeconomy should be detailed at the regional level, making it possible to track regional features of its development.

Conclusions

The conducted research demonstrates the presence of a high bioeconomic potential possessed by Ukraine's economic sector and the growth of this potential due to the bioeconomy's quantitative, not qualitative, component processes. Therefore, to ensure the efficiency and effectiveness of bioeconomic transformation processes, it is important to thoroughly and systematically assess the processes taking place in the system, in our case in the fields of bioeconomy, as a system, and to ensure the adoption of necessary management actions and strategic decisions at all levels.

Methodological approaches for managing complex systems of various types and hierarchical levels require the implementation of appropriate algorithms based on modeling, taking into account modern control mechanisms. In our opinion, the use of the proposed SEE-management algorithm proposed by Yarmolenko and Burennikova (2015), which is based on a developed management mechanism directly related to the efficiency and effectiveness of the processes taking place in the transforming system, provides the possibility of achieving a high level of efficiency and effectiveness of the process of bioeconomic transformation. The structure of the mechanism used takes into account the peculiarities of the complex dynamic system functioning, which is a bioeconomic system, in the conditions of a changing external environment, as well as a set of goals, tasks, functions, principles, methods, means, techniques, factors, technologies and available resources in combination with the adoption of managerial solutions. It is important that the implementation of the SEE-management mechanism takes place using the SEE-analysis, takes into account the SEE-reserves and SEE-risks, and enables the realization of SEE-forecasts of the possible further development of systems, which requires appropriate SEE-actions – making management decisions. The implementation of the SEE-management methodology by the example of the process value-added generation of bioeconomic sector enterprises shows that it could be applied in practice to make scientifically based management decisions at the micro-level, and, if necessary, at the meso- and macro-levels by appropriate linking with the help of complex models of performance components.

Transformational processes can be caused by a complex interaction of certain driving forces, such as population growth and technological innovation, or by political or social actions, which is more realistic in the context of Ukraine. Depending on a country's context and its interactions with other economies, for example, in the form of trade and knowledge transfer, bioeconomic transformation can follow one or more of the four pathways outlined above, with different possible effects. After the full-scale invasion of Russia on the territory of Ukraine, negative structural changes that require structural solutions became obvious. The rapprochement of Ukraine with its powerful resource potential and the EU is an obvious trend for development in the coming decades. It is also obvious that it is necessary to develop a further vision of integrating Ukraine's agricultural complex into European space, which is currently perceived with fear. However, taking into account the fact that the EU countries cannot fully provide themselves with biomass for the development of their own bioeconomy, it is likely that the construction of new processing capacities to increase the value of agricultural products in Ukraine, which could be attracted by the EU market, depending on global markets and the development of transport costs, may be a win-win solution for all parties. This new reality calls for a new direction for the EU Green Deal. The bioeconomic transformation of Ukraine can become a new impetus for the bioeconomy in the EU. It must not only strengthen strategic production (food, animal feed, production of biofuels and biomaterials, etc.), but also help stabilize agricultural markets and provide long-term support for the Ukrainian economy and democracy.

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