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CIRCULAR BIOECONOMY DEVELOPMENT FACTORS IN SELECTED EUROPEAN UNION COUNTRIES (2012-2021)

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ABSTRACT: Circular bioeconomy constitutes one of the key developmental strategies of the European Union. Understanding the conditions for the advancement thereof is crucial for successfully implementing these principles in daily production and consumption. The aim of this study was to identify the key drivers within bioeconomy indicators. The research was conducted based on bioeconomy indicators classified by the European Commission. Data were obtained from Eurostat and FAOSTAT, describing phenomena recognised as bioeconomy indicators for the period from 2012 to 2021. The analysis covered selected EU countries – member states that joined the community before 2004. The data underwent exploratory factor analysis, which identified five groups of indicators linked to underlying factors. These factors were identified as: Innovation, Institutional Conditions: Implementation of the Circular Economy Strategy, Institutional Conditions: Implementation of Sustainable Development Policies, Resource Efficiency, and Support and Expansion of Forested Areas. The analysis also identified certain risks associated with the development of bioeconomy, as measured by the indicators defined by the European Commission. The mentioned risks relate to a decline in food purchasing power and a decrease in biodiversity.

KEYWORDS: bioeconomy, bioeconomy indicators, bioeconomy development factors, European Union, risks

Introduction

The origins of the bioeconomy strategy in the European Union date back to the early 1980s when the European Commission (EC) was in charge of preparing, managing and implementing the EU Framework Programs in Biotechnology and Life Sciences, which in 2002 became the basis for the Strategy on Life Sciences and Biotechnology. The implementation of this strategy made policymakers aware of the potential of Knowledge-Based Bio-Economy (Patermann & Aguilar, 2018). The bioeconomy has proven to be a promising solution in a world requiring the reduction of greenhouse gas emissions and the search for alternatives to fossil fuel sources and petroleum-based materials. In the first bioeconomy strategy published in 2012, called «Innovating for Sustainable Growth: a Bioeconomy for Europe», the European Commission communicates the need for a radical change in the approach to the production, consumption, processing, storage, recycling and disposal of biological resources to cope with the growing world population, the rapid depletion of many resources, increasing pressure on the environment and climate change (European Commission, 2012). The goal was a more innovative, low-emissions economy which reconciles demands for sustainable agriculture and fisheries, food security and the sustainable use of renewable biological resources for industrial purposes, while also ensuring biodiversity and environmental protection. Its implementation plan was based on three pillars: developing new technologies and processes for the bioeconomy, developing markets and competitiveness in bio-economy sectors, and pushing policymakers and stakeholders to work more closely together (Schmidt et al., 2012). This strategy has become the subject of discussion in the area of its impact on sustainable development. It was pointed out, among others, that the strategy leans towards weak sustainability, and a balance between environmental, social, and economic dimensions is missing (Ramcilovic-Suominen & Pülzl, 2018), as well as a lifecycle perspective. This includes ensuring that the entire process, from biomass production to end-product use, is sustainable and equitable, whereas the presented strategy emphasises research and innovation but lacks comprehensive lifecycle considerations. Finally, there were concerns about a potential conflict of interest in the food vs fuel / industrial goods formula (De Besi & McCormick, 2015; Hassan et al., 2019). Therefore, in 2018, the bioeconomy strategy was updated, among other things, emphasising the need to base it on sustainable practices. The European bioeconomy strategy aims to achieve five key goals: *ensure food security, manage natural resources sustainably, reduce dependence on non-renewable resources, limit and adapt to climate change, strengthen European competitiveness and create jobs*. The way the bioeconomy is understood in the European Union places particular emphasis on the issue of sustainability: *The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services. To be successful, the European bioeconomy needs to have sustainability and circularity at its heart. This will drive the renewal of our industries, the modernisation of our primary production systems, the protection of the environment and will enhance biodiversity* (European Commission, 2018). This definition roots the understanding of the bioeconomy in the broader concept of a circular economy, where cascading biological cycles complement those of non-renewable materials. The circularity of the bioeconomy and the cascading nature of resource use reduce the environmental footprint and enable the efficient use of resources (Abad-Segura et al., 2021; Jensch et al., 2022).

Making the circular bioeconomy a key strategy of the European Union is an important step in the context of becoming independent from non-renewable resources, creating a competitive advantage in the regional and global context and strengthening the position of the social group of farmers and the importance of rural areas. However, the implementation of bioeconomy principles and the creation of national strategies are not uniform in the entire EU.

The aim of this study is to diagnose the factors that influence the development of the bioeconomy, expressed by the indicators proposed by the European Commission, in selected European Union countries, and understand the process of entering the era of circular bioeconomy and the processes and phenomena that constitute it.

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An overview of the literature

The bioeconomy's resource is biomass, and its most important producers are the agricultural and forestry sectors. Agriculture is recognised as the main supplier of biomass for food, feed and other bio-based industries in the EU, alongside the forestry sector (Vlad & Toma, 2022). However, the image of agricultural countries, those where agriculture is a major sector of the economy or countries with high availability of renewable resources, does not determine the development pattern and dynamics of the bioeconomy nor the readiness to include it in national development strategies (Table 1).

Table 1. The potential of biomass production in the context of the implementation of the national bioeconomy strategy

Country	Bioeconomy strategy on the national level (status for October 2023)	Percentage of employment in agriculture (status for 2022)	Cultivated land (%)	Share of forest in total area (%)	European Eco-Innovation Index (status for 2022)
Austria	**1**	**4**	**17.3**	**46**	**173.86**
Belgium	**0**	**1**	**28**	**22**	**99.78**
Denmark	**0**	**2**	**59**	**15**	**167.43**
Finland	**1**	**4**	**7.4**	**66**	**178.01**
France	**1**	**3**	**35.2**	**32**	**130.65**
Germany	**1**	**1**	**34.7**	**32**	**141.18**
Greece	**0**	**11**	**28.6**	**30**	**101.59**
Ireland	**1**	**4**	**15.4**	**12**	**110.39**
Italy	**1**	**4**	**31.4**	**32**	**129.39**
Luxembourg	**0**	**1**	**24.6**	**34**	**179.02**
Netherlands	**1**	**2**	**30.9**	**10**	**118.78**
Portugal	**1**	**5**	**19.7**	**36**	**105.69**
Spain	**1**	**4**	**34**	**37**	**116.43**
Sweden	**0**	**2**	**6.4**	**63**	**160.95**
Bulgaria	0	6	31.4	35	57.73
Croatia	0	6	17.5	34	88.81
Republic of Cyprus	0	2	13	19	94.65
Czech Republic	0	3	42	34	110.98
Estonia	1	3	15	54	115.52
Hungary	0	4	50.5	22	81.15
Latvia	1	7	18.7	53	105.37
Lithuania	0	5	35.4	34	103.75
Malta	0	1	34.38	1	79.76
Poland	0	8	37.5	30	67.37
Romania	0	18	41	29	84.59
Slovakia	0	3	29.3	40	94.49
Slovenia	0	4	9.7	58	115.86

1 – dedicated bioeconomy strategy on the national level; 0 – lack of dedicated bioeconomy strategy. EU member countries that joined before 2004 are marked with bold.
Source: authors' work based on European Commission (2023, 2024a, 2024b), World Bank (2024), The World Factbook (2024) and Eurostat Statistics explained (2024).

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65% of member states that joined the EU before 2004 have a bioeconomy strategy, alongside 15% of those that joined after 2004. On average, employment in agriculture in the 'old' EU countries is less than 3.5% of the labour force, in the 'new', it is almost 5.5%. On average, arable land in the 'old' 14 covers 26.6% of the countries' area, in the 'new' 13 it is almost 30%. In a similar approach, the forest area is 36% vs. 34%. Differences in the area of the bioresources between the old and new member states are not significant. The methods of their use by individual countries seem to be crucial, enabling the full potential of biomass to be used, which requires an innovative approach. In terms of eco-innovation, the 'new' 13 countries have a lower index (average 92,31) than the old member states (average 136,65).

Biological resources alone do not encourage countries to look for strategic solutions for their use. Countries rich in renewable resources but unable to harness their potential in innovative ways may fall victim to the resource curse, where the abundance of natural resources can lead to poor economic growth, high levels of poverty and political instability (Rosser, 2006; Sachs & Warner, 2001). Research on the phenomenon of the resource curse proves that institutional order is an important factor enabling their effective use. Strong institutions can reverse the negative relationship between natural resource intensity and economic growth, reversing the resource curse (Boschini et al., 2013). In this context, it can be expected that highly developed countries of the European Union will benefit from the use and transformation of the resource biomass. However, this process depends on innovation. Schütte (2018) state that the condition for changes in industry necessary for the bioeconomy development is a committed research and innovation policy. In the context of innovation, the European Union is highly polarised, which may pose a threat to the process of uniform implementation of the circular bioeconomy. Eco-innovation leaders have remained in their positions for years, and the 'chasing' countries are not closing the gap (see Figure 1).

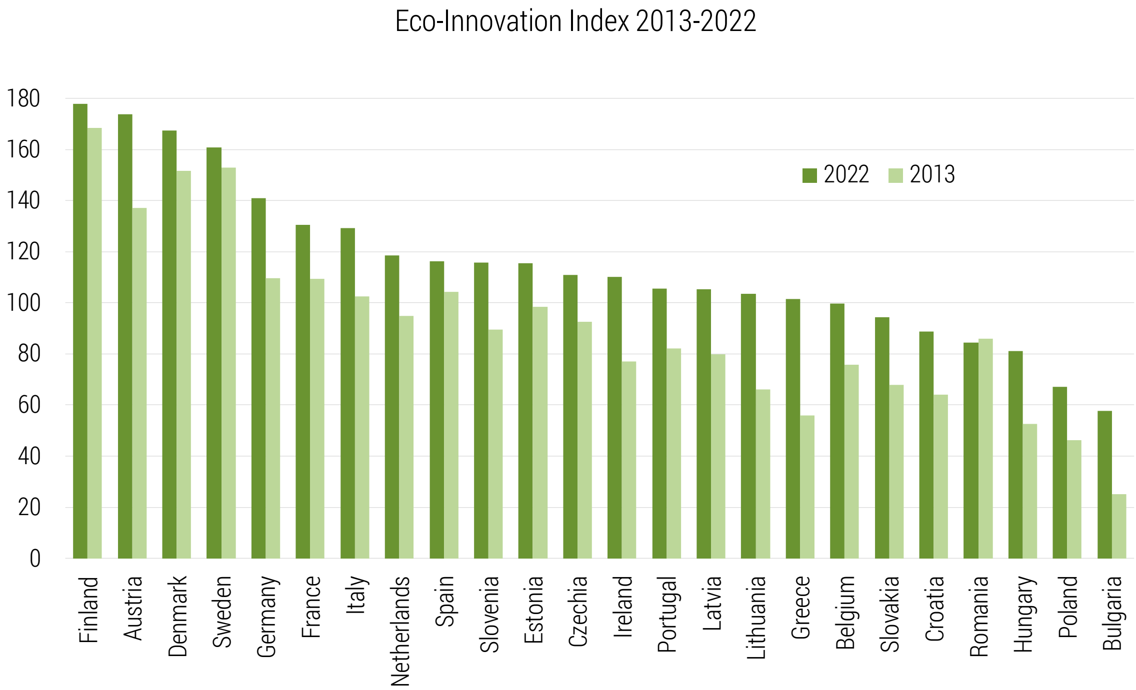

Figure 1. Eco-Innovation Index of chosen EU countries 2013-2022

Source: authors' work based on https://green-business.ec.europa.eu/eco-innovation_en [21-10-2024].

This duality in the context of implementing the bioeconomy in Europe was noticed by Cristea et al. (2020). In their study, the authors showed a different impact of the same phenomena on the development of the bioeconomy. In the case of countries that joined before 2004, both innovations and higher levels of education have a positive impact, in the 'new' 13 countries, this impact has not been observed. Perhaps this is due to the insufficient level of financing and the existence of a threshold effect in the area of eco-innovation. Research indicates that in developing countries below the thresh-

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old, the effect of innovation measured by the number of patents is not significant in terms of impact on economic growth for developed and developing countries. However, after exceeding the optimal threshold, the effect becomes positive for the entire sample and developed countries (Inglesi-Lotz et al., 2020). A similar relationship may occur in the area of bioeconomy. Czyżewski et al. (2021) write about the importance of the level of economic development for the bioeconomy. The level of economic development influences the growth of the bioeconomy, with highly developed countries benefiting from high spending on research and development and eco-innovation, while moderately developed countries are exploiting their agricultural sectors. This is a warning to European Union countries that base their GDP on traditional sectors of the economy and consumption, limiting policies that stimulate innovation. In addition to the above issues of resources, innovation, institutional governance, and the size of the economy, research indicates a number of phenomena that are conducive to the development of the bioeconomy. At the institutional level, researchers emphasise the need to formulate long-term, coherent strategies involving multiple bioeconomy stakeholders. These strategies should be based on the engagement of both public and private partners, taking into account the positions and interests of civil society (Kirs et al., 2022; Patermann & Aguilar, 2018; Bell et al., 2018). This is related to social awareness and social acceptance of the concept of bioeconomy as well as its products (Woźniak et al., 2021).

Research methods and materials

Measuring the circular bioeconomy is a difficult task due to the fact that it cuts across numerous sectors. One measurement approach is to assess the contribution of the bioeconomy to GDP, employment levels or turnover (Bracco et al., 2018). However, understanding the bioeconomy as a path to the goal of sustainability, this approach lacked both social and environmental elements. Other indicators cited in the literature include The Substitution Share Indicator (SSI), which can monitor the bioeconomy transitions by comparing bio-based substitute products to fossil-based ones (Jander & Grundmann, 2019) or relate to the measurement of progress in the bioeconomy, taking into account the level of achievement of the objectives of the EU bioeconomy strategy, bio-based sectors development, biomass and food production, supply, demand factors, resource availability and bioeconomy policies (Kardung et al., 2021). In turn, Alviar et al. (2021) propose as key indicators for measuring the progress of the bioeconomy sustainable development, knowledge, research, added value, employment and greenhouse gas emissions. For the purposes of this article, the proposal of the European Commission was adopted, which implemented a set of indicators to monitor the level of the bioeconomy. They have been divided into 5 main groups:

1. Ecosystem conditions (incl. Forests, agriculture land, marine and freshwater ecosystems and urban ecosystems),
2. Primary production systems (incl. Production of biomass, employment in primary sector, value added from primary sector, emissions from primary production),
3. Secondary production systems (incl. Uses of biomass, employment in secondary sector, value added from secondary sectors, products),
4. Waste and circularity (incl. Food waste, biowaste, circularity and recovery), Trade (European Commission, 2024a).

The research material, in the form of numerical data, was obtained from the bioeconomy monitoring system (European Commision, 2024a). The data covered European Union countries and spanned the period from 2012 to 2021. All countries participated in the study, with the exception of Luxembourg, Malta, and Cyprus. The final analysis included EU countries that joined the community before 2004. Not all variables were complete or continuous. In selected cases, the dataset was supplemented with data from Eurostat and FAOSTAT. The study began in 2012 when the first bioeconomy strategy was implemented in the EU. The EU bioeconomy monitoring system comprises 43 indicators, but due to incompleteness, not all were included in this study. In some cases, indicators originally proposed by the EC were replaced with similar indicators from other sources. Table 2 lists the indicators analysed.

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Table 2. List of bioeconomy indicators included in the study

Variable	Original indicator (EC database)	Unit	Data source
V1	Agricultural factor income per annual work unit (AWU)	Index 2015=100	Eurostat (2024a)
V2	Biomass domestic extraction	Tones per capita	Eurostat (2024b)
V3	Biomass waste treatment	Tones per capita	Eurostat (2024c)
V4	Biomass recycling	Tones per capita	Eurostat (2024d)
V5	Circular material rate	%	Eurostat (2024e)
V6	Energy productivity	EUR / kg of the petrol equivalent	Eurostat (2024f)
V7	Food purchasing power	% GDP	Eurostat (2024g)
V8	Forest growing stock	1000 m^3 per capita	Eurostat (2024h)
V9	Government support to agricultural research and development	EUR per capita	Eurostat (2024i)
V10	Intensification of farming (high)	% high input farm in UAA	Eurostat (2024j)
V11	Intensification of farming (medium)	% medium input farms in UAA	Eurostat (2024j)
V12	Intensification of farming (low)	% low input farms in UAA	Eurostat (2024j)
V13	Livestock density index	Livestock Units/UAA	FAOSTAT (2024)
V14	net GHG emissions (emissions and removals) from agriculture	1000 ton per capita	Eurostat (2024k)
V15	net GHG emissions (emissions and removals) from LULUCF	1000 ton per capita	Eurostat (2024k)
V16	Recycling rate of municipal waste	%	Eurostat (2024l)
V17	Share of organic farming in utilised agricultural area	% UAA	Eurostat (2024m)
V18	Share of renewable energy in gross final energy consumption	%	Eurostat (2024n)
V19	Share of renewable energy in gross final energy consumption	%	Eurostat (2024o)
V20	Biomass domestic consumption	Tones per capita	Eurostat (2024r)
V21	Added value of agriculture, forestry, fishing, food, beverage and tobacco industry, paper and paper products	EUR per capita	Eurostat (2024p)

Source: authors' work based on https://ec.europa.eu/eurostat/databrowser/ [02-06-2024] and https://www.fao.org/faostat/en/ [02-06-2024].

The chosen indicators refer to the five areas of bioeconomy monitoring brought forward in the introduction. The study used exploratory factor analysis (EFA). EFA identifies variables, called factors, that explain correlation patterns found within sets of observed variables. Factor analysis can be used to establish hypotheses regarding causal mechanisms, which is how it was utilised in this article. EFA allows for the identification of underlying factors (known as latent) that can explain the interdependencies between multiple observable variables. These factors represent common dimensions or constructs that are not directly measured but influence observable variables. The JASP program was used to examine the interrelationships of variables describing the bioeconomy (Wagenmakers, 2023). EFA was conducted using polychoric correlations, extraction with the minimum chi-square method, parallel analysis, and oblimin oblique rotation. Items with factor loadings < 0.50 or loadings on more than one factor were eliminated. A factor loading between 0.4 and 0.5 is an acceptable range within which an item can belong to a factor (Comrey & Lee, 2013). A Kaiser-Meyer-Olkin test was also conducted to confirm that the data prepared were suitable for performing EFA (Kaiser, 1974).

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Results of the research

The first step involved a procedure conducted to examine the interdependencies between bioeconomy indicators across the full sample of 25 EU countries from 2012-2021. This approach did not allow the identification of hidden factors and interdependencies between the indicators. This is likely due to the still noticeable differences in the development of socio-economic structures between the so-called “old” and “new” European Union countries. The convergence process has intensified the economic growth of the ‘new’ countries compared to the “old” ones (Szczepańska-Woszczyna et al., 2022). Financial inclusion in the community, capital, labour, economic openness and even energy consumption all affect economic growth, but in the case of “new” countries, this impact is stronger (Huang et al., 2021). In this respect, it can be hypothesised that the socio-economic processes in the European Union take on varying shapes and dynamics and enter into different causal relationships depending on whether they involve countries that joined the EU after 2004 or those that joined earlier. Therefore, in the next step, the analysis excluded member countries that joined the EU after 2004, focusing on the countries highlighted in bold in Table 1. As a result, 5 factors were identified (Figure 2), explaining 75.40% of the total variance. The Kaiser-Meyer-Olkin (KMO) test result (KMO = 0.538) indicated that the collected data were suitable for conducting EFA. The structure of the obtained factors is presented in Table 3.

Table 3. Structure of the obtained factor loadings for individual variables

Variable	Item / Factor	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
V2	Biomass domestic extraction	0.967				
V20	Government support to agricultural research and development	0.959				
V9	Biomass domestic consumption	0.745				
V21	Value-added	0.737				
V7	Food purchasing power	-0.609				
V4	Biomass recycling		0.998			
V13	Circular material rate		0.794			
V5	Livestock density index		0.776			
V3	Biomass waste treatment		0.763			
V16	Recycling rate of municipal waste		0.622			
V17	Share of organic farming in utilized agricultural area			0.949		
V18	Share of renewable energy in gross final energy consumption			0.787		
V6	Energy productivity				0.744	
V1	Agricultural factor income per annual work unit (AWU)				0.573	
V10	Intensification of farming (share of high input farms in UAA)				0.473	
V8	Forest growing stock					0.661
V15	Net GHG emissions (emissions and removals) from LULUCF					-0.522

Exploratory factor analysis was conducted using the JASP software (Wagenmakers, 2023), employing polychoric correlations, extraction with the minimum chi-square method, parallel analysis, and oblimin oblique rotation. Items with loadings < 0.47 or loadings on more than one factor were eliminated, resulting in 5 factors explaining approximately 75.40% of the total variance (Table 4).

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Table 4. Characteristics of obtained factors

Factor	Sum of squares of charges	Variance percentage	Cumulative variance
Factor RC 1	3.997	0.235	0.235
Factor RC 2	3.679	0.216	0.451
Factor RC 3	2.079	0.122	0.574
Factor RC 4	1.807	0.106	0.680
Factor RC 5	1.258	0.074	0.754

The elimination of irrelevant factors resulted in a scree plot (Figure 2), which presents the final factor values describing the bioeconomy in the selected countries.

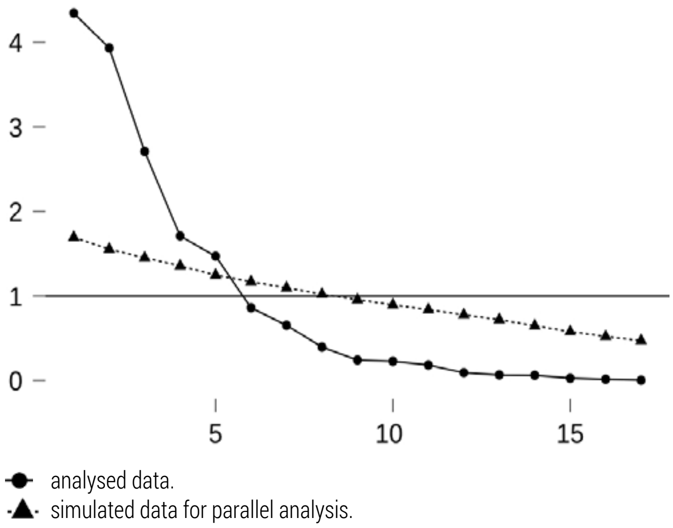

Figure 2. Scree plot showing the eigenvalues of the factors

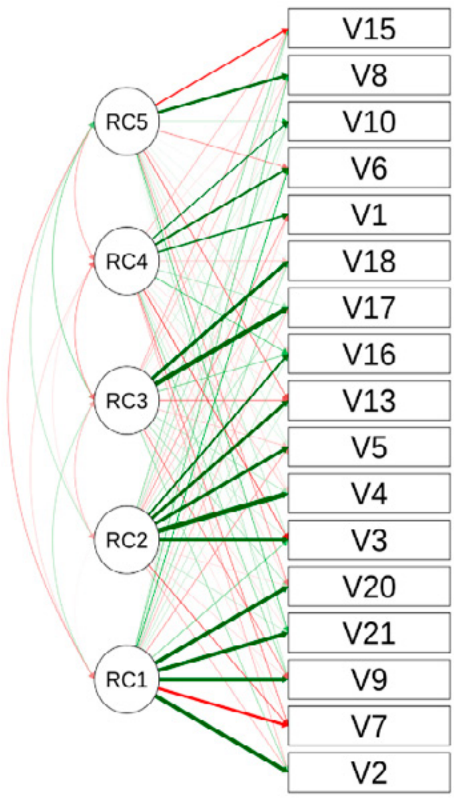

Figure 3. Path diagram of the exploratory factor analysis for variables describing the bioeconomy phenomenon in countries that formed part of the European Union before 2004

The Kaiser-Meyer-Olkin (KMO) test result (KMO = 0.538) indicated that the collected data were suitable for conducting EFA.

The analysis showed the existence of 5 groups of indicators behind which there are latent factors. A schematic breakdown is shown in Figure 3.

The analysis identified 5 underlying factors behind the following interrelated phenomena, which comprise indicators of the bioeconomy:

RC1: Innovativeness: Biomass domestic extraction (V2), Food purchasing power (V7, interrelatedness), Government support to agricultural research and development (V9), Biomass domestic consumption (V20), Added value of agriculture, forestry, fishing, food, beverage and tobacco industry, paper and paper products (V21).

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RC2: Institutional conditions: Implementation of the circular economy strategy: Biomass waste treatment (V3), Biomass recycling (V4), Circular material rate (V5), Livestock density index (V13), Recycling rate of municipal waste (V16).

RC3: Institutional conditions: Implementation of the circular economy strategy: Share of organic farming in utilised agricultural area (V17) as well as Share of renewable energy in gross final energy consumption (V18).

RC4: Resource efficiency: Agricultural factor income per annual work unit (V1), Energy productivity (V6), Intensification of farming (share of high input farms in UAA) (V10).

RC5: Support and expansion of forest areas: Forest growing stock (V8) as well as net GHG emissions (emissions and removals) from LULUCF (V15).

Discussion

The analysis of the EU countries that joined the community before 2004 allows us to indicate that the development of the bioeconomy is run by 5 factors that influenced its evolution: innovations, implementation of the circular economy strategy and previous sustainability policies supporting organic farming and the development of energy from renewable sources, efficiency of resource use and method of implementing forest management.

The first identified factor is innovation. This factor is associated with the following indicators: Biomass domestic extraction (V2), Food purchasing power (V7, with an inverse correlation), Government support for agricultural research and development (V9), Biomass domestic consumption (V20), Added value of agriculture, forestry, fishing, food, beverage and tobacco industry, paper and paper products (V21). Research is quite clear in demonstrating the importance of innovation in biomass production and processing (Antar et al., 2021). Innovative approaches to agronomic practices, the use of beneficial organisms, signaling compounds between microorganisms and plants, and genome editing enable increased biomass production. New crops and cultivation systems, including perennial grasses, crop rotation, legumes, and cover crops, can produce large quantities of biomass while improving resource efficiency and reducing environmental impact (Anex et al., 2007). Of course, innovations also contribute to more efficient and broader biomass processing and its conversion into bio-based products and energy (Tshikovhi & Motaung, 2023; Faaij, 2006). The relationship between state investment in innovation and the level of innovation is obvious and explains the relationship of Government support to the agricultural research and development (V9) indicator. Higher expenditure on research and development is significantly correlated with the innovation potential (and economic growth) in EU countries (Kiseľáková et al., 2020; Archibugi et al., 2020), and innovation is a self-propelling mechanism, supported, for example, by information technology. However, government support, including grants and financial incentives, has the greatest impact, significantly improving business outcomes and innovation performance (Rosário et al., 2022; Cano-Kollmann et al., 2016). It can be said that innovations breed further innovations if the administration creates the right environment for this process. Another indicator related to the aforementioned and associated with innovation is Biomass domestic consumption (V20). Biomass consumption is growing thanks to innovation because, in addition to food consumption and animal breeding, the consumption of innovative biobased materials and renewable bioenergy is increasing. Research on innovative bioenergy shows that technological progress in the thickening and processing of biomass significantly increases its use for energy production (Bajwa et al., 2018). In 2023, the annual demand for biomass in the EU was expected to increase from 7 EJ to 10 EJ, with forest biomass and agricultural biomass playing key roles (Wieruszewski & Mydlarz, 2022). It is estimated that by 2050, bioenergy will cover 27% of primary energy demand (Mandley et al., 2021), which means increasing demand for biomass but also emphasis on the development of Bioenergy with Carbon Capture and Storage to enable the implementation of climate goals (Mandley et al., 2021). The development of biobased materials and biopolymers in the market also contributes to the increase in biomass consumption. The increase in demand is mainly due to sugar and starch plants (Escobar et al., 2018). In the last decade, it was predicted that by 2050, biopolymers could replace up to 11% of the market, leading to an increase in demand for biomass (Schipfer et al., 2017). Also, a growing market for biobased chemicals, from 2018 to 2030 is projected to be four times higher than its fossil-based counterpart, requiring

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increased demand for starch and plant oils (van Leeuwen et al., 2023), and the economic importance of biomass in the context of implementing the assumptions of the Green Deal and searching for innovations enabling zero-emission will lead to an increase in demand for it (Vitunskienė et al., 2022).

An indicator dependent on innovation and inversely correlated with the other four is Food purchasing power (V7). We are, therefore, dealing with a situation in which the increase in the extraction and consumption of biomass is accompanied by an increase in expenditure on research and development and innovation in the primary biomass production sector and an increase in the added value of bioeconomy products (including food). At the same time, a decline in the purchasing power of food is observed. In the context of the phenomena described above, it is possible to explain this inverse correlation by the increase in demand for biomass, biofuels, bioproducts and raw materials for food and feed production discussed above. This may favour the intensification of primary production, which in turn leads to an increase in demand for biomass and an increase in prices resulting from the law of demand. Growing demand may also mean greater competition for limited resources related to its production, such as land, water and energy, and as a result, higher food prices. Thanks to innovations and investments in R&D, bioeconomy products (including food) can gain added value. Higher added value may result from higher quality, new products, or new processing methods, which increases the price of these products on the market. This phenomenon has been observable since the beginning of the 21st century. Mitchell (2008) states that the most important factor in the rise of food prices was the large increase in biofuel production in the U.S. and the EU (Mitchell, 2008). These observations are confirmed by Choi et al. (2019), who state that most bioeconomy scenarios lead to increasing food prices (the average food price index increases by about 11% in the EU) (Choi et al., 2019). The inverse correlation found in this research may, therefore, prove that this trend actually persists.

Another indicator dependent on innovation is the Added value of agriculture, forestry, fishing, food, beverage, tobacco industry, and paper products (V21). The effectiveness of innovations contributes to increased added value in these sectors by optimising production processes and improving the quality of raw materials and final products. This is evident in the food sector, where advanced processing enhances value by preserving nutritional content, extending shelf life and marketability, improving biological safety, and enhancing sensory qualities (Neema, 2023), quality, functionality, and packaging (Sharif et al., 2018). Similarly, in the pulp and paper industry (Onufrey & Bergek, 2020), where product innovation, energy and material efficiency, sustainability and a focus on customer needs for higher value-added services are the main drivers of competitiveness (Toppinen et al., 2017).

Another factor influencing the separate group of bioeconomy indicators is RC2, which can be understood as Institutional conditions: implementation of the circular economy strategy, which is related to indicators: Biomass waste treatment (V3), Biomass recycling (V4), Circular material rate (V5), Livestock density index (V13), Recycling rate of municipal waste (V16). Indicators V3, V4, V5, and V16 are directly related to the implementation of circular economy principles. Indicator V13: The livestock density index directly affects the amount of organic waste, such as manure, which can be processed or used in a circular economy. Thus, it is logically connected to the other indicators. Animal production plays a key role in closed-loop food systems, and manure-based energy production contributes to material loop closure (Koppelmäki et al., 2021). The mere link between the circular economy and the bioeconomy is a necessary association, as these are interdependent concepts, as expressed by the butterfly diagram (Ellen MacArthur Foundation, 2019). The simultaneous implementation of the bioeconomy and the circular economy enhances the sustainable use of natural resources by improving their efficiency and reducing negative environmental impacts (Abad-Segura et al., 2021; D'Amato et al., 2017).

The subsequent factor, RC3, was defined as: Institutional conditions: implementing sustainable development policies. RC3 affects two indicators: Share of organic farming in utilised agricultural area (V17) and Share of renewable energy in gross final energy consumption (V18). Although these indicators may seem unrelated at first glance, they are the result of some of the oldest environmental strategies that residents of old Europe have been familiar with for decades. Public spending on renewable energy research and development in Europe dates back to the early 1970s (Bointner et al., 2016). In terms of organic farming, in the 1970s non-governmental organisations such as IFOAM, FNAB or FiBL were established, which contributed greatly to the development of organic farming standards. The European Union adopted a regulation on organic farming (No. 2092/91) in 1991, which became law in 1993 (MA & Joachim, 2006). These strategies, essential for sustainable development and the Green Deal, are deeply rooted in member countries, and the implementation thereof contributes to the development of the circular bioeconomy. They can, therefore, be considered as specific prerequisites for circular bioeconomy strategies.

Factor RC4 was defined as Resource efficiency: Agricultural factor income per annual work unit (V1), Energy productivity (V6), and Intensification of farming (share of high input farms in UAA) (V10). One factor that affects all of the above indicators is the pursuit of increasing resource use efficiency. Increased agricultural intensification can lead to higher yields and productivity per unit of area. This may result in higher incomes for farms, which could translate into higher wages in agriculture. Review studies indicate that conventional intensification increases yields by 20.3%. However, this comes at the cost of an 8.9% loss in biodiversity across all production systems and species groups (Beckmann et al., 2019). Pellegrini and Fernández demonstrated that global crop production tripled from 1961 to 2014 and that advances in fertilisers, irrigation, and other technologies led to improved energy efficiency while land use increased by only 10%. Another aspect of the established interdependence is that agricultural intensification often leads to higher technical efficiency and specialised production skills (Pellegrini & Fernández, 2018). This effect may be associated with rising labour costs in agriculture. At the same time, it poses a certain risk, as specialisation in agriculture weakens the economic resilience of farms and increases their sensitivity to market fluctuations (Roest et al., 2017).

The last identified factor of bioeconomy development refers to the Forest growing stock (V8) and net GHG emissions (emissions and removals) from LULUCF (V15) indicators, which are inversely related. This factor RC5 has been defined as support and expansion of forest areas. The interrelationship between the two indicators mentioned above is well documented in the literature; forests absorb significant amounts of CO2, contributing to carbon storage in biomass and soil (Petersson et al., 2022; Whitehead, 2011; Verma & Kumar Ghosh, 2022).

All identified factors are interconnected in a network of dependencies. In some instances, these are negative dependencies. This means that implementing the circular bioeconomy, as described by the European Commission's indicators, is a complex process where the processes realising the formation of the bioeconomy can simultaneously be in mutual conflict.

Conclusions

The development of the bioeconomy in the European Union countries that joined the community before 2004 is determined by the following factors:

- innovativeness of the economy,
- institutional conditions: promoting policies and disseminating circularity practices as well as earlier sustainable development policies: renewable energy and organic farming,
- resource efficiency,
- afforestation.

In assessing the identified factors, there is a valid conclusion that these factors are related to actions dependent on the awareness and knowledge of policymakers and society. The advancement of the bioeconomy in "old" member states thus depends primarily on human-controlled aspects rather than the wealth of resources. This observation is not novel, as it echoes the identification of the resource curse phenomenon. The identification of interdependencies among indicators within specific factors has also led to several observations regarding potential risks associated with bioeconomy development in "old" EU countries, assuming a goal of improving the bioeconomy indicators defined by the European Commission. The first potential risk arising from bioeconomy progress is a decrease in food purchasing power, which may affect the perception of well-being and access to nutritional value among Europeans. However, the study only covered "old" EU countries, which limits the generalizability of the findings. The biomass production capabilities in "new" countries may mitigate this risk. The latter risk stems from the temptation to increase the efficiency of biomass production, which is related to the intensification of this production and may translate into deepening planetary problems, including the loss of biodiversity.

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This study is marked by limitations primarily arising from the imperfections in the bioeconomy indicator databases. The identified factors of bioeconomy development pertain to selected EU countries; for a complete picture, it is essential to continue research concerning the "new" EU member states. The direction and dynamics of bioeconomy development in various regions of the European Union exhibit distinct characteristics, opportunities, and threats.

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The contribution of the authors

Conceptualisation, M.P., M.N. and M.S.; literature review, M.P., M.N. and M.S.; methodology, M.P., M.N. and M.S.; formal analysis, M.P. and M.S.; writing, M.P., M.N. and M.S.; conclusions and discussion, M.P., M.N. and M.S.

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CZYNNIKI ROZWOJU CYRKULARNEJ BIOGOSPODARKI W WYBRANYCH KRAJACH UNII EUROPEJSKIEJ (2012-2021)

STRESZCZENIE: Cyrkularna biogospodarka stanowi jedną z kluczowych strategii rozwoju Unii Europejskiej. Zrozumienie uwarunkowań jej rozwoju jest kluczowe dla sukcesu wdrożenia tych zasad w codzienną produkcję i konsumpcję. Celem niniejszego badania było zidentyfikowanie czynników stojących za postępem w obrębie wskaźników biogospodarki. Badanie zostało przeprowadzone w oparciu o wskaźniki biogospodarki sklasyfikowane przez Komisję Europejską. Dane pozyskano z Eurostatu i FAOstatu. Opisywały one zjawiska uznane za wskaźniki biogospodarki w okresie od 2012-2021. Analizie poddano wybrane kraje Unii Europejskiej – kraje członkowskie, które dołączyły do wspólnoty przed 2004 rokiem. Dane zostały poddane eksploracyjnej analizie czynnikowej. W badaniu wyodrębniono pięć grup wskaźników powiązanych z ukrytymi czynnikami. Czynniki te zostały zidentyfikowane jako: Innowacyjność, Uwarunkowania instytucjonalne: Realizacja strategii GOZ, Uwarunkowania instytucjonalne: wdrażanie polityk rozwoju zrównoważonego, Efektywność wykorzystania zasobów oraz Wsparcie i rozbudowa obszarów leśnych. Podczas analizy zidentyfikowane zostały również pewne ryzyka, z którymi wiąże się rozwój biogospodarki mierzony zdefiniowanymi przez KE wskaźnikami. Ryzyka te dotyczą spadku siły nabywczej żywności i spadku bioróżnorodności.

SŁOWA KLUCZOWE: biogospodarka, wskaźniki biogospodarki, czynniki rozwoju biogospodarki, Unia Europejska, ryzyka

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