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The structural change of the economy in the context of the bioeconomy

Zoltán Lakner, ConceptualizationData curationMethodologyWriting – original draft[a], Judit Oláh, Formal analysisWriting – review & editing[b,c,*], József Popp, Data curationMethodology[a,c], Ervin Balázs, Writing – review & editing[d]

[a] Hungarian University of Agriculture and Life Sciences, Gödöllő 2100, Hungary
[b] Faculty of Economics and Business, University of Debrecen, Debrecen 4032, Hungary
[c] College of Business and Economics, University of Johannesburg, Johannesburg 2006, South Africa
[d] ELKH ATK Centre for Agricultural Research, Martonvásár 2462, Hungary

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ABSTRACT

The bioeconomy is a highly complex, cross-sectorial concept covering all sectors and systems that rely on biomass. Based on the analysis of the size of bioeconomy in the V4 countries it can be concluded that the sustainable transition is a great challenge and can be achieved by developing national circular bioeconomy strategies. It is extremely difficult to analyse the contribution of different sectors to the performance of the circular bioeconomy. Currently, the contribution of different sectors to the biomass-based economy is very complex, therefore a strategic socio-economic planning and optimal resource allocation is necessary to achieve the goals of the bioeconomy. This paper aims to determine the place and role of the bioeconomy in the structural change of the linear economy, based on detailed matrices of in- and output relations between different sectors. Based on the input-output matrices, as well as centrality and flow metrics of network analysis, the role of the bioeconomy in the linear economy, its multiplicative effects and future research implications are analysed.

1. Introduction and literature review

The bioeconomy is a relatively new concept, originally defined by Martinez (1998) as “all economic activity derived from scientific and/or research activity focused on understanding mechanisms and processes at genetic/molecular levels and its application to industrial process”. Since its origin, a plethora of definitions has emerged (Maciejczak and Hofreiter, 2013). According to the definition of the European Commission (2020) the bioeconomy means using renewable biological resources from land and sea, like crops, forests, fish, animals and micro-organisms to produce food, materials and energy”. According to Frisvold et al. (2021), there is no clear-cut definition of the bioeconomy because there are different approaches to this relatively new phenomenon. Other authors emphasise the importance of the application of biotechnology (Bueso and Tangney, 2017), or the role of biological resources and the ecological aspects (Philp et al., 2013). Some publications (Morrison and Golden, 2015) have included agriculture and forestry, forest products, natural-fibre (e.g. cotton) textiles, biorefining, bio-based chemicals, enzymes, and bioplastic bottles and packaging, but excluded traditional agriculture, food and feed processing and biofuel production (Oláh et al., 2020).

In the framework of this research a more holistic approach to the bioeconomy is used because (1) there are no well-defined borders between the use of the food and non-food applications of biological materials, since some parts of the same agricultural product go for food, while others for non-food use (e.g. maize for food, feed, energy and bioplastic production), (2) a considerable proportion of food is used for non-food use, as food waste and by-products, (3) this approach makes a comparative analysis between different projects possible, and (4) the economic stability of agriculture will determine the economic viability of the non-food use of biomass.

In the last few years, an increasing number of studies have been published concerning the economic role of the bioeconomy, based on sophisticated econometric methods. Loizou et al. (2019) analysed the bioeconomy by input-output modelling and quantified the importance of bio-based sectors in economic development. Brizga et al. (2019), as well as O’Donoghue et al. (2019), applied the input-output analysis of the bioeconomy to quantify the environmental aspects. Finally, input-output matrices have also been applied in the analysis of regional aspects in different papers (Lehtonen and Okkonen, 2013; Mainar-Causapé et al., 2020).

* Corresponding author at: Faculty of Economics and Business, University of Debrecen, Debrecen 4032, Hungary.
E-mail addresses: lakner.zoltan.karoly@uni-mate.hu (Z. Lakner), olah.judit@econ.unideb.hu (J. Oláh), popp.jozsef@uni-mate.hu (J. Popp), balazs.ervin@atk.hu (E. Balázs).

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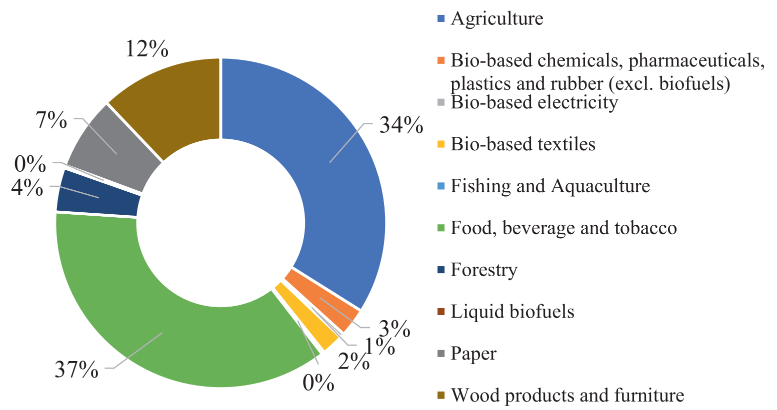
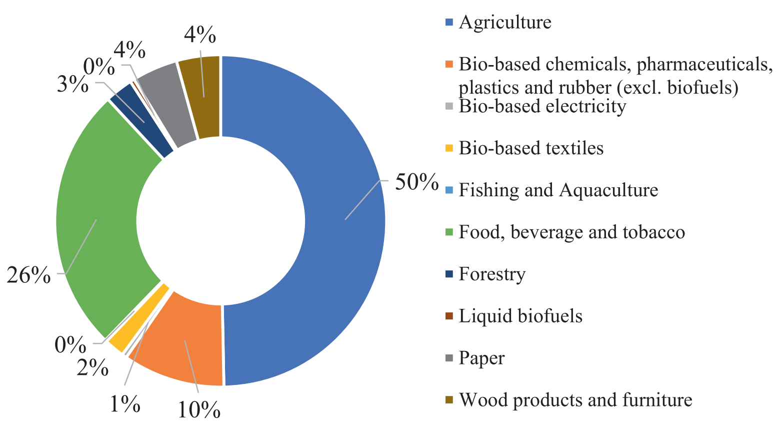


Value added in total: €33 billion

Fig. 1. Value added in the Polish bioeconomy, by sectors in 2017.
Source: Ronzon et al. (2018).



Value added in total: €9 billion

Fig. 2. Value added in the Hungarian bioeconomy, by sectors in 2017.
Source: Ronzon et al. (2018).

The majority of the publications covering this topic have focused on one product category, one sector (Karvonen et al., 2017), on regional aspects of the problem or on regional aspects of the bioeconomy (Philippidis et al., 2014). The objective of this study is more complex: to offer a general picture based on input-output analysis and the modelling of the potential effect of the replacement of fossil-based products with bio-based products. The geographical focus of the investigation is the Visegrad countries (V4), namely Poland, the Czech Republic, Slovakia and Hungary in particular. The V4 countries have numerous similarities, in both economic development and biomass potential.

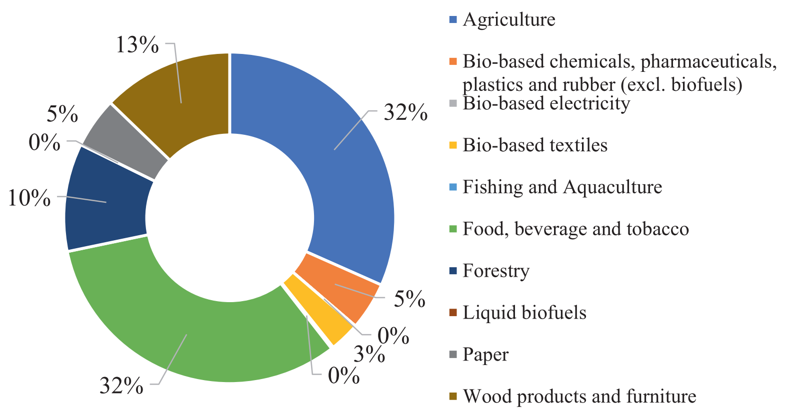
In 2017, the value added of the bioeconomy in the V4 countries ranged from 4 billion to 33 billion euros. Between 2008 and 2017 the value-added production of the V4 bioeconomy grew from €44 billion to €55 billion, i.e. by 25% (Figs. 1–4). The share of the V4 group in the EU bioeconomy was 9% in 2017. The bioeconomy in the EU represented 4.2% but generated a higher share of value added in the V4 countries (4.6% in the Czech Republic, 4.7% in Slovakia and 7% in both Poland and Hungary).

In 2017 the average productivity in terms of value added per person employed in the bioeconomy of the V4 was lower than the EU average. This value added per person was €13,000 in Poland, €23,000 in Slovakia and €24,000 in the Czech Republic and Hungary, compared to the EU average of €34,000. Between 2008 and 2017, productivity in value added per person employed in the bioeconomy increased by 20–40% in the V4 countries, but remained at least 30% lower than the EU average (Ronzon et al., 2018).

Agriculture and the food industry (food, beverages and tobacco) constituted 60–75% of the added value in the V4 bioeconomy in 2017. On average, two thirds of value added was generated by the agriculture and food sectors, followed by wood products and furniture (4–13%), the forest-based bioeconomy (3–16%), paper (4–7%) and textiles (2–4%). Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber accounted for 3-–10 % of the value added (3% in Poland and 5–10% in the other three countries). Between 2008 and 2017, with the exception of bio-based chemicals, pharmaceuticals, plastics and rubber (excluding biofuels) production, the share of other sectors in value added output did not show any real change, and agriculture and the food industry remained the dominant sector with a two-thirds share of value added (Figs. 1–4).

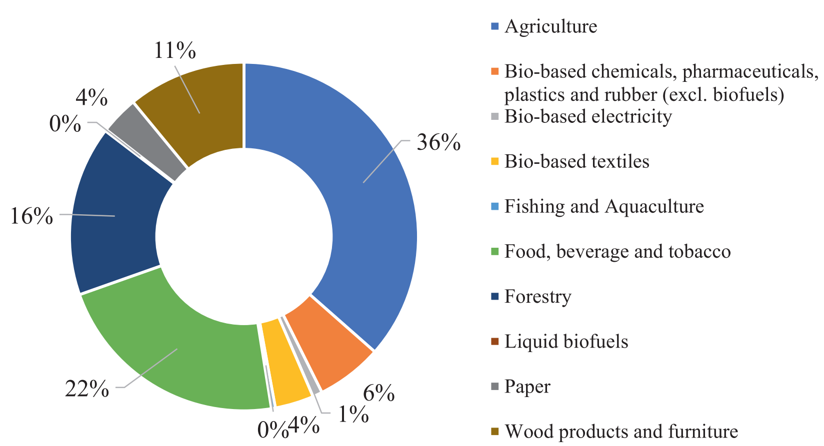
The V4 is a group of small countries (5–10 M inhabitants), except for Poland (38 M inhabitants), which – with the exception of Poland – are not large enough to be domestic market driven. Slovakia, the Czech Republic and Hungary can be regarded as assembly countries with a small and open economy. Most of the V4's exports go to the EU market. From the energy perspective, there is a need to reduce dependence on nonrenewable sources, as well as on imports (50–60% energy dependency), in addition to improving the energy intensity in the overall economy. Production of renewable energy plays an important role; however, the V4 countries have set their 2020 goal at less than a 20% share of renewable energy in gross final energy consumption. The 2020 target of the V4 countries for a 13–16% share of energy from renewable sources in gross final consumption of energy was met in 2020 (Eurostat, 2021).

Biomass from agriculture dominates biomass flows; however, waste and by-streams of biobased production could be a resource for the development of novel value chains. Wood-based biomass accounts for about 20–30% of the biomass supply, with exports of roundwood and wooden



Value added in total: €9 billion

Fig. 3. Value added in the Czech bioeconomy, by sectors in 2017.
Source: Ronzon et al. (2018).



Value added in total: €4 billion

Fig. 4. Value added in the Slovakian bioeconomy, by sectors in 2017.
Source: Ronzon et al. (2018).

pellets. Capture fisheries and aquaculture are also included in the bioeconomy, with imports of fishmeal, oil and seafood. Novel bio-based industries with high added value and less labour intensity generate high value added per employee. The labour market is less specialised in the V4 bioeconomy than in the old Member States, and labour productivity in agriculture, food and forestry sectors is lower than the EU average.

Bioeconomy-related policy must be integrated into overall economic development policy, so as to increase productivity by reducing energy intensity as well. There are several options for a transition to a sustainable and circular bioeconomy in the V4 countries. These include learning from the development of the automotive industry (*R&I* activity, dual educational system, supply network), reducing energy dependency from imports by the enhancement of energy efficiency and the extensive use of renewable energy sources in the existing bio-based industry, expanding freshwater aquaculture (higher value added per person employed), strengthening education in bioeconomy related topics and generating spin offs of new value-added chains for bio-materials from waste and by-product streams from field to fork production (60–75% of the value added in the current bioeconomy). The bioeconomy exists in all economic activities related to the production and processing of biomass.

Global climate action and the need to reduce greenhouse gas emissions to zero by 2050 in the EU is a major challenge for V4 countries. It can be achieved by developing national circular bioeconomy strategies and new value chains and biomass flow to create biobased products within a closed loop. If the V4 countries do not address the prioritisation of bio-based carbon, the region will remain an assembly economy, lag behind in international competitiveness and fail to meet the goals of the sustainability transition. In the absence of a bioeconomy policy, the bioeconomy will not be able to maintain its existing share due to the dynamic EU macroeconomic environment which is moving towards the carbon neutral vision of Europe in 2050.

In summary, it can be concluded that the bioeconomy concept is rapidly gaining in importance, and its analysis by sophisticated econometric methods is a problem of general professional interest, although limited knowledge is available beyond the simple descriptive statistics of the bioeconomy. The goal of the study is to offer a more in-depth analysis of the structure of the bioeconomy and its effect on economic development in general.

This paper is structured as follows. The introduction section presents the different definitions of, and approaches adopted in, the bioeconomy and gives a detailed picture of the role of the bioeconomy in the V4 countries. The methodology section gives a broad overview of the concept of input-output analysis and the application of network theory in the analysis of input-output tables, as well as on data sources. In the results section a new method for determining the volume and share of the bioeconomy is presented and validated on the example of the USA, followed by a network analysis of the bioeconomy, using the example of Poland and presenting the economic impact of biomass use on industrial sectors in the V4 countries, and finally by an influence analysis of the impact of the bioeconomy on economic development in Hungary. In the conclusions section hypotheses are validated and future research needs outlined.

2. Hypothesis development

In the framework of this paper three hypotheses will be tested:

H_1: Based on input-output analysis there is a favourable possibility to determine the proportion of bioscopies in different countries.

H_2: The main sectors of the biomass-based economy are of considerable strategic importance in the development of the economy.

H_3: Increasing bio-based materials in industrial use (e.g. in the chemical and car industries) will contribute to general economic development. This hypothesis is based on the fact that it is well documented that the in- and output side openness of the biomass-based sectors (mainly agriculture and forestry) is relatively high (Harun et al., 2018; Loizou et al., 2019), leading to an increasing share of bio-based materials in non-food sectors (e.g. the construction industry, automobile production, the energy sector, chemicals and pharmaceuticals), accompanied by economic growth, environmental protection and new jobs.

3. Materials and methods

3.1. Input-output analysis

The intellectual roots of input-output analysis can be traced back to the beginnings of modern economic thinking by Phillips (1955), but it is directly linked to the analytical framework of Wassily Leontief (Василий Васильевич Леонтьев), a German-born Soviet-American economist, who constructed (Leontief and Strout, 1963), the famous equation to describe the structure of economies, consisting of n sectors:

$$\bar{p} = \bar{\bar{A}}\bar{p} + \bar{d} \tag{1}$$

where p is the production vector of different sectors, and A is the matrix of utilisation of the branches in the reproduction process. This is an $n \times n$ matrix, describing the utilisation of the output of sector j by sector i. This matrix is called the consumption matrix or - in normalised form - the technology coefficient matrix. d is the external demand vector. In the case of an open economy $d \neq 0$, while in a closed economy $d = 0$.

The Leontief-inverse of the matrix of utilisation shows the effect of changes in the demand of sector i for the goods produced by sector j:

$$L = (I - A)^{-1} \tag{2}$$

Originally, the Leontief model was developed for analysis of national economies, but there is a possibility to construct multi-regional models, too (Fu et al., 2021; Leontief and Strout, 1963).

Based on this approach, other multipliers can be defined. For example, the household income multiplier vector indicates that an additional unit of final demand for sector i output would generate a new figure for household income, taking into consideration all the direct and indirect effects (Emonts-Holley et al., 2020). This furnishes additional information when we try to determine the optimal distribution of subsidies. The value-added multiplier quantifies the changes in the value-added creation of different sectors as a reaction to changes in demand (Shishido et al., 2000). The indicator of value added is considered more suitable for measuring a given sector's contribution to economic performance than changes in gross output.

Leontief's model makes it possible to evaluate the effect of changes in demand in production, employment and income generation in a society. The summary of the column and row values of different industries gives information about the relative importance of various sectors.

Lahr (1993) has analysed the role of different sectors in national economies and has emphasised that the majority of resources should be spent on sectors which are capable of generating economic development in backward (supplying) and forward (absorbing) branches of the national economy.

The sum of the rows of the Leontief inverse matrix can be considered backward linkages or output multipliers of different sectors. These can be calculated as follows:

$$X_j = \sum_{i=1}^{n} b_{ij} X_i + I_j$$

The total backward linkages are the column sum of the inverse value of the Leontief coefficients

$$FL_j = \frac{n^{-1} \sum_{i=1}^{j=n} g_{ij}}{n^{-2} \sum_{j=1}^{j=n} \sum_{i=1}^{i=1} g_{ij}} \tag{3}$$

Forward linkages can be considered the row sum of the Goshian inverse (Theil and Gosh, 1980).

$$FL_j = \frac{n^{-1} \sum_{i=1}^{j=n} g_{ij}}{n^{-2} \sum_{j=1}^{j=n} \sum_{i=1}^{i=1} g_{ij}} \tag{4}$$

Key sector analysis offers two synthetic indicators for each sector: one for the quantification of backward and one for forward linkages (Miller and Blair, 2009). At the same time, the spill-over effects of the increasing demand of one or another sector have to be taken into consideration.

Methodically, the question arises: how can the effect of the change in one element of the flow between the sectors be quantified? This means that a change in the interpectoral flow of one element influences other interpectoral flows (Sonis et al., 1996). In addition, numerous algorithms have been developed to calculate these "spin-off" effects. In the simplest case, the change in one element (a_{ij}) in the technical coefficient matrix generates incremental changes in the matrix. The first order (primary) effects can be quantified by the first order field of influence indicator, which is equal to multiplying the j_{th} row of the Leontief matrix by the i_{th} column (Okuyama et al., 2002). At the same time, increases will occur in another value in the matrices, therefore further calculations are made to understand the effects of the changes. This logic leads to a recursive calculation. For comparison of the effects of changes in different sectors, the authors have calculated the sum of all first order fields of influence in order to compare the effect of changes in different sectors.

The causes of changes in the structure of input-output matrices can be analysed by the output decomposition method (Sonis et al., 1996). This method separates the changes in I/O matrices into demand effects and changes in technology, indicated by the Leontief-inverse and by the interaction of these two terms. The same decomposition can be calculated to determine whether the changes occur due to the changes within the sector (self-generated) or outside of the sector (non self-generated).

3.2. Network analysis

The input–output table can be considered a network, and network-analysis - a relatively new interdisciplinary approach (Albert and Barabási, 2002) – can be applied to its investigation (Borgatti et al., 2009; Li et al., 2017). Network analysis portrays the relationships between entities (in our case: sectors) as a graph.

This graph A=(V,E) consists of a set of vertices (nodes) (V) and a set of edges (E). In our case the vertices are the sectors, and the edges are the value-flows between them. Each edge (i,j) is directed and has a non-negative weight, a_{ij}. By definition, the graph may contain self-loops because a given sector can be a consumer of its own products.

To understand the relative importance of different sectors in the value flow, the centrality concepts of network analysis can be applied. The position of a given node in a network is rather hard to qualify on the basis of one indicator alone because it is always a difficult question how the centrality position of an actor can be qualified (e.g. a node might have many connections but these connections are rather weak), while other nodes have just a few, but strong, connections. Therefore, a wide range of network centrality indicators has been developed.

There are numerous measures of centrality; moreover, even a mushrooming of these indicators can be experienced. The simplest one is network centrality, which expresses the number of ties a node has. Closeness centrality is a measure of the "embeddedness" of a node in the network. If this measure is high, it means that numerous nodes are close to the investigated one (Crescenzi et al., 2016). In the case of an analysis of a human network, a high degree of closeness centrality can be interpreted as popularity. In the case of sectors, this measure expresses the importance of a given sector in the material and value flow between sectors of the national economy. Degree centrality is another measure of the "embeddedness" of a node in the network (Yustiawan et al., 2015). The eigenvector centrality measures the influence of a node, taking into consideration the influence of the neighbouring nodes (Ruhnau, 2000).

Network centrality is a further indicator suitable for the characterisation of a given node based on its position in the network and calculated by the clustering of edges. In the opinion of Wang et al. (2011) this value is more appropriate to characterise the position of different nodes than the values mentioned above. Node centrality is a highly complex question, which is why there are different indicators of it. In our case, we have applied four indicators to determine the centrality of different sectors. The first of these is closeness centrality, which is a widely used indicator of node positions. The higher value this indicator has, the more central is the position of the node.

Information centrality represents the harmonic mean lengths of paths which come to an end at the given node. The network centrality measure developed by Tang et al. (2015) takes into consideration the centrality of nodes and their relationships with their neighbours. The eigenvector centrality (prestige score) is an indicator of the influence of a given node. This indicator expresses the importance of nodes by joining them to the given node (Ruhnau, 2000). The weighted degree is another indicator of the centrality of edges in a given network (Opsahl et al., 2010).

3.3. Data sources

Calculations are based on the input/output (I/O) data of different national economies downloaded from the worldmrio.com database (Source: https://www.worldmrio.com/). This is considered a highly authentic source of I/O data globally (Lenzen et al., 2012). For the calculation of biomass use in different countries a relatively simple indicator has been developed. Following the logic of the approach to quantify the bioeconomy, the sectors have been divided into two categories (Ronzon et al., 2017).

The first category covers the following sectors (applying the nomenclature of the I/O matrices of Eurostat): (1) products of agriculture, hunting and related services; (2) forestry, logging and related services, fish and other fishing products, services incidental to fishing, (3) food products and beverages, tobacco products, (4) leather and leather products, (5) wood, wood products and cork (except furniture); articles of straw and plaiting materials; (6) pulps, paper and paper products.

The second category of sectors includes all other sectors of national economies. The calculation of the proportion of biomass in other sectors in addition to the six product groups was based on the proportion of biomass in the total inputs used by these sectors. This approach has three advantages: (1) the calculation of the proportion of the bioeconomy in the different sectors can be done by basic matrix arithmetic; (2) it is universal, because the proportion of the bioeconomy can be calculated for dozens of countries with I/O tables available; (3) it offers the possibility of including all sectors related to biomass use.

This method has been tested based on the example of the US bioeconomy because (1) this is the largest bioeconomy in the world, (2) the statistics offer very detailed information on different sectors - the standard classification divides the economy into 60 sectors, the US classification into 428 sectors, (3) the US statistical system was the first to apply the input-output calculation method, and therefore it is capable of providing highly coherent and quality-controlled data on economic interactions between sectors for biomass use (Fig. 5).

4. Results

4.1. The role of the bioeconomy in the USA (as an example)

The USA has been chosen as an example, as outlined in the methodology section, for the following reasons. The USA has the largest economy in the world, the statistical database used for the investigation provides accurate and very detailed information of the biomass use in over 400 sectors and the USA was the first country to apply the input-output calculation method based on coherent and quality-controlled data of the economic interactions between sectors.

The turnover of the US bioeconomy increased from 803 billion USD in 1990 to 1050 billion USD or 5.8% of GDP in 2015. This represents a 30% increase of turnover in 25 years, while its share of GDP did not change and remained around 13%. The share of the bioeconomy in the linear economy showed a high degree of stability (Fig. 6).

Based on our calculations the size of the US bioeconomy in 2015 was 1050 billion current U.S. dollars. This estimation is similar to the figures published by Frisvold et al. (2021) and the National Academies of Sciences and Medicine (2020). Both sources highlighted that in 2016 the total contribution of the bioeconomy to U.S. GDP was estimated to be around USD 960 billion, accounting for about 5.1% of U.S. GDP.

4.2. Network analysis in the Polish bioeconomy (as an example)

In first phase of the investigation the most important network centrality indicators were determined for 2015.

As an example, the centrality indicators of different sectors in the Polish economy are presented in Table 1. Obviously, not all indicators are suitable in the same degree for differentiation of the centrality position of sectors. For example, the closeness centrality is rather similar in numerous cases, but the other indicators may differ from each other. Agriculture and forestry play a central role in the present linear economy of Poland; however, agriculture's share of Polish GDP was just 2.3% (The GlobalEconomy, 2021). This paradox can be explained by the central position of agriculture in the value flows of the national economy. For example, the eigenvector centrality of the sector "Products of agriculture, hunting and related services" (hereinafter: agriculture) is higher than the same indicator in the manufacturing industries, and the degree centrality of the food industry is higher by one order of magnitude than the indicator of industrial sectors (Table 1). This can be explained by the fact that agriculture represents totally different sectors of the economy, e.g. machinery industry, including the value chain. The high level of the intermediate production of the agricultural and food sector (packaging materials, chemicals, etc.) explains the considerable network centrality of these sectors.

The results are in line with the findings of Blöchl et al. (2011) and Barba et al. (2020) on the structural change of the national economies.

4.3. Changes in the economic position of the bio-based sector in the V4 countries

Comparing the IO matrices in 2005 and 2015, important changes can be seen in the V4 countries on the basis of the input-output decomposition method (Table 2). Based on this method authors divided the sources of change into two categories, namely demand-driven and technology driven factors. Both categories can be further divided into intra and extra sectoral changes. For example, the technology development in plant production by the introduction of new varieties counts

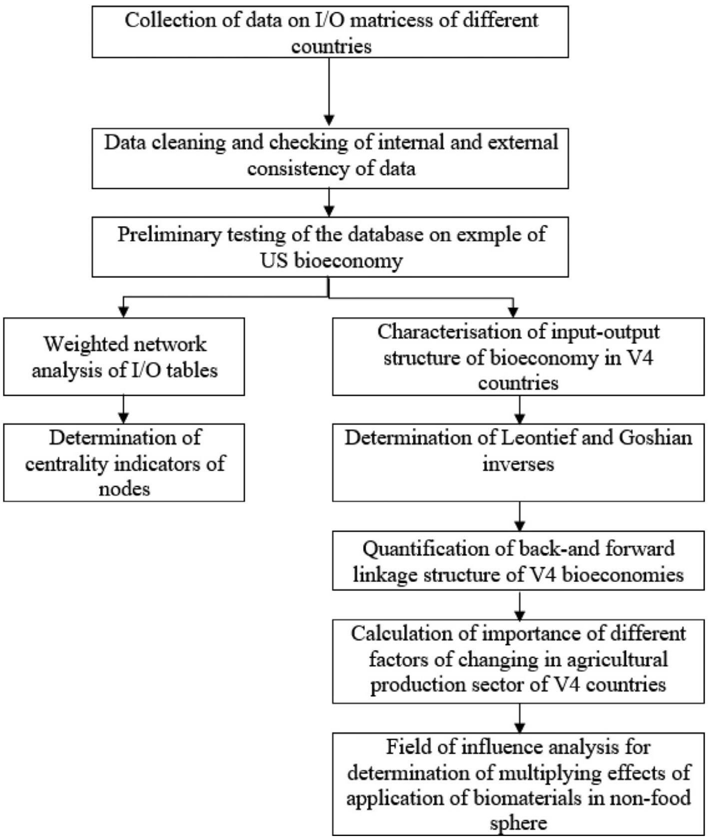


Fig. 5. Flowchart of the investigation on the example of the US bioeconomy.

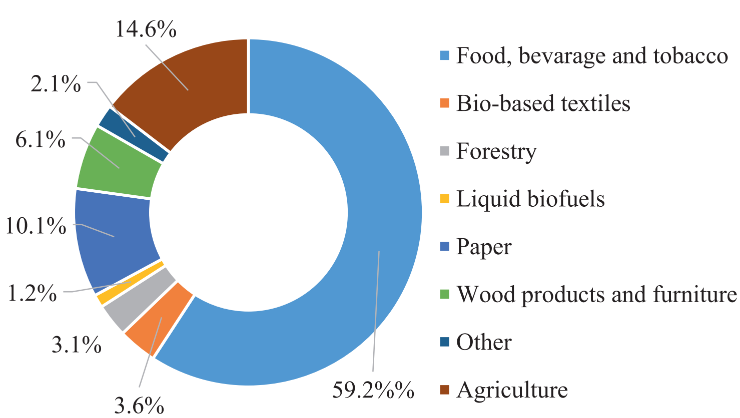


Fig. 6. Turnover in the US bioeconomy, by sectors in 2015.
Note: sectors with a higher than 1% share of the total turnover of the US bioeconomy are included.
Source: Authors' own calculations, based on I/O tables for the USA, downloaded from https://www.worldmrio.com.

Table 1
Network centrality indicators of the main sectors of the Polish national economy, based on the year 2015.

Sectors	closeness	eigenvector	degree	network
Products of agriculture, hunting and related services	6408	0.579	4.16E + 10	3458
Products of forestry, logging and related services	6407	0.004	3.60E + 09	1224
Fish and other fishing products; services incidental of fishing	6406	0.005	4.85E + 08	925
Food products and beverages	15638	0.659	5.70E + 10	3081
Tobacco products	6407	0.003	8.31E + 08	626
Textiles	6407	0.009	3.74E + 09	1110
Leather and leather products	6407	0.003	1.09E + 09	509
Wood, wood products and cork (except furniture); articles of straw and plaiting materials	6408	0.029	1.13E + 10	1765
Pulp, paper and paper products	9053	0.031	7.79E + 09	1675
Furniture; other manufactured goods	9053	0.020	8.85E + 09	1384
Average of the national economy	5712	0.000	5.23 + 08	8

Source: Authors' own calculations, based on the I/O table for Poland (base prices).

Table 2
Decomposition of the change in I/O matrices (billion USD) in the agriculture, forestry and aquaculture sectors of the V4 countries between 2005 and 2015.

Country	Sector	ΔX_t	ΔX_{td}	ΔX_{tL}	$\Delta X_{int.t}$	$\Delta X_{int.d}$	$\Delta X_{int.L}$	$\Delta X_{ext.t}$	$\Delta X_{ext.d}$	$\Delta X_{ext.L}$
SKV	Agriculture	0.330	2.925	-0.122	0.023	1.820	0.023	0.307	1.105	-0.145
	Forestry	0.262	-0.036	-0.023	-0.064	-0.602	-0.062	0.325	0.566	0.039
	Aquaculture	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000
HUN	Agriculture	-2.064	6.677	-2.392	-0.088	0.923	0.358	-1.977	5.754	-2.750
	Forestry	-0.029	0.219	-0.049	-0.002	0.131	-0.004	-0.027	0.088	-0.045
	Aquaculture	0.000	0.005	0.000	0.000	0.004	0.000	0.000	0.001	0.000
CZE	Agriculture	-0.810	4.646	-0.852	-0.019	0.417	0.034	-0.791	4.230	-0.886
	Forestry	0.134	-0.139	0.145	0.031	0.309	0.045	0.103	-0.449	0.099
	Aquaculture	0.000	0.049	0.000	0.000	0.045	0.000	0.000	0.004	0.000
POL	Agriculture	10.709	0.883	-3.291	-0.826	-5.498	-0.155	11.535	6.381	-3.136
	Forestry	14.9637	-4.782	14.751	-11.147	-3.450	-6.462	16.785	-1.331	-13.8290
	Aquaculture	0.763	-0.082	-0.666	-0.008	-0.136	-0.005	0.771	0.054	-0.661

Source: Authors' own calculations, based on the I/O tables of the V4 countries
Legend
ΔX_t Total change
ΔX_t Total change as a consequence of change in final demand
ΔX_{tL} Total change as a consequence of change in technology
$\Delta X_{int.t}$ intra-sectoral (self-generated) total change
$\Delta X_{int.d}$ intra-sectoral (self-generated) change as a consequence of change in final demand
$\Delta X_{int.L}$ intra-sectoral (self-generated) change as a consequence of change in technology
$\Delta X_{ext.t}$ inter-sectoral (non-self-generated) total change
$\Delta X_{ext.d}$ inter-sectoral (non-self-generated) change as a consequence of change in final demand
$\Delta X_{ext.L}$ inter-sectoral (non-self-generated) change as a consequence of change in technology

Table 3
Results of influence analysis in the Hungarian bioeconomy, 2015.

	Products of agriculture, hunting and related services	Products of forestry, logging and related services	Fish and other fishing products; services incidental of fishing	Food products and beverages	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	Pulp, paper and paper products
Textiles	2.10	2.96	0.72	1.27	0.93	1.03
Wearing apparel; furs	2.83	3.97	0.97	1.70	1.25	1.38
Leather and leather products	2.89	4.06	0.99	1.74	1.28	1.41
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	5.50	7.72	1.89	3.30	2.43	2.68
Pulp, paper and paper products	2.55	3.58	0.87	1.53	1.12	1.24
Rubber and plastic products	2.45	3.44	0.84	1.47	1.08	1.19
Radio, television and communication equipment and apparatus	2.96	4.15	1.02	1.78	1.30	1.44
Motor vehicles, trailers and semi-trailers	3.00	4.21	1.03	1.80	1.32	1.46
Other transport equipment	2.92	4.10	1.00	1.76	1.29	1.42
Construction work	3.81	5.35	1.31	2.29	1.68	1.85
Wholesale trade and commission trade services, except for motor vehicles and motorcycles	3.77	5.30	1.29	2.26	1.66	1.84
Hotel and restaurant services	3.14	4.42	1.08	1.90	1.38	1.53

Source: Authors' own calculations, based on the I/O tables of the V4 countries.

as an intra-sectoral change, while the decreasing bargaining power of the food industry with the food chains counts as an inter-sectoral change.

The role of the bioeconomy in the national economy can be easily traced back by the decomposition of the I/O matrices as described in the methodology chapter. The results of this analysis are summarised in Table 2. The negative signs of the Leontief matrix show the lack of modernisation in these sectors. It is very important to highlight that the main impact of the biomass production was created by non-agricultural sectors: e.g. trade (so-called non-self-generated effects).

To the best of our knowledge this is the first attempt to analyse the structural changes in the V4 region by this method.

4.4. The impact of the bioeconomy on economic development – results of influence analysis, using Hungary as an example

Influence analysis offers a complex picture of inter-sectoral effects. The results of fit analysis highlight the importance of the non-food use of biomass because the application of these products for non–food use results in a direct and important multiplication effect. Table 3 shows the results of influence analysis in the case of Hungary, because its economy can be characterised by an extremely high level of economic complexity (Adam et al., 2021; De Chalendar and Giraud, 2017). The model applied gives information on all possible combinations of sectors. For example, it can be calculated to what extent economic growth is influenced by the sale of a one unit (e.g. USD) increase in agricultural products, for example, to the chemical industry. An increasing number of publications highlight the role and the technical/technological applications of such specific combinations (Bledzki et al., 2010; Bracco et al., 2018; Scarlat et al., 2015), but to the best of our knowledge this is the first attempt to quantify the macroeconomic effects of these changes.

The results of influence analysis highlight the importance of "greening" the economy. For example, a unit increase of agricultural products in the textile industry can generate 2.1 units of additional demand in the national economy. The use of more wood instead of plastics in the radio and telecommunications industry could generate an additional 4.15 units of demand in the economy.

The methodology applied above offers favourable perspectives for future research. These findings are in parallel with the results of other European countries (Ferreira et al., 2021), offering the possibility to obtain a general picture of the impact of the bioeconomy on socio-economic development.

5. Conclusions

The analysis of the bioeconomy in the V4 countries shows that meeting the goals of the European Green Deal is a big challenge and the sustainable transition can be achieved by developing national circular bioeconomy strategies. This study demonstrates that the role of the bioeconomy can be investigated by the analysis of input/output tables. Methods suggested for the calculation of the role of the bioeconomy in the linear economy are robust. These methods cover relatively easily generalizable approaches based on the countries analysed, the origin of the *I/O* tables and the size of the bioeconomy quantified.

In the study three research hypotheses have been tested and the results have confirmed that the analysis of *I/O* matrices is a suitable method for the evaluation of the place and role of the bioeconomy in national economies. This fact supports the H_1 hypothesis and is in line with the results of Loizou et al. (2019) and Jurga et al. (2021). The result can be explained by the specific role of the biomass-based sectors in the economy, which supply a wide variety of sectors ranging from the machinery to the catering sectors. This fact highlights the central role of the bioeconomy, which leads to an intensive development of the biomass-based economy with higher added value (Popp et al., 2021). On the other hand, the results show the decreasing efficiency of agriculture, forestry and fisheries based on the decomposition of the *I/O* matrices in the V4 countries for the period 2005–2015.

Furthermore, the results have confirmed that the biomass-based sectors are of considerable importance in the development of the economy. This fact conforms hypothesis H_2 and supports the previous results of numerous authors (Farcas et al., 2021; Iost et al., 2019; Ludwik and Wicka, 2016; Woźniak and Twardowski, 2018). Finally, the results of the study show the favourable economic effect of the transition to bio-based material use, confirming hypothesis H_3.

Based on the results, some general directions of future research can be outlined. The bioeconomy concept is a relatively new one and the following main directions for further research should be highlighted:

1 At the micro-economic level there is a need to understand the cost-benefit relations in the case of different technologies. This is a highly complex issue because the rapid development of biotechnology necessitates the practical application of a wide range of innovations from genetic engineering to automatization and the big data concept.
2 The bioeconomy has a considerable influence on the environment. Based on complex lifecycle analysis in depth studies on a case-by-case basis should determine the complex environmental effects of different developments in the bioeconomy. For example, the question arises of whether an increasing use of cotton in the textile industry will influence the availability of other natural resources. A striking example is the rapid shrinkage of the Aral See due to the irrigation of cotton crops in Uzbekistan (Raskin et al. 1992), or the devastation of European forests in the Middle Ages (Ahvenainen, 1996).
3 At the macro-economic level, it is possible to integrate the bioeconomy into the fabrics of modern economies. The main goal is to increase the share of bio-based materials in the overall economy; however, non-targeted subsidies could create or strengthen the "rent-seeking" behaviour of farmers, leading to decreasing biomass production. For example, the Common Agricultural Policy of the European Union has not been able to motivate farmers to adopt farm innovations (Recanati et al., 2019).
4 The socio-economic level is a highly complex question because there is no clear vision on how society can and will accept the innovations of technology in general and biotechnology in particular. For example, the majority of French society accepts atomic energy but German society prefers the application of renewable energy resources, including bioenergy, to atomic energy. On a global scale similar differences can be seen in the case of the application of modern genetics. These two examples show rather clearly the importance of understanding public awareness and attitudes.

As a summary, it can be concluded that the bioeconomy can be an engine of economic development, but numerous aspects are still unknown. The inclusion of uncertainties in the construction of national I/O tables, the harmonisation of the different statistical systems and the optimisation of biomass use in non-food sectors for the development of the bioeconomy are all open-ended questions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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