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Potential of the bioeconomy in Visegrad countries: An input-output approach

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ABSTRACT

The EU has placed high priority on the expansion of the bioeconomy with the aim to reduce the use of non-renewable resources, to mitigate climate change, and to develop prospering local economies. However, only few Member States have defined quantitative economic or environmental targets for the bioeconomy in their policy strategies as measurement of the bioeconomy is not straightforward. This study uses an input-output analysis to quantify economic as well as environmental indicators for measuring the bioeconomy in the Visegrad countries (Slovakia, Czech Republic, Poland and Hungary). The current and the potential size of the bioeconomy are derived based on scenarios of minimum, medium and maximum association of partially bio-based goods with the bioeconomy. Our results suggest that currently the bioeconomy contributes 13% to the value of economic output, 10% to value added, 15% to total employment, and 20% to emissions of greenhouse gases in the Visegrad region (with a variation of 8 percentage points among individual countries). There is still potential for a transition towards a bioeconomy, especially in the production of textiles and wearing apparel, chemical products, pharmaceutical products, plastics, furniture, and energy where fossil-based inputs could be substituted by bio-based resources.

1. Introduction

In recent years, policymakers and analysts all over the world have placed high priority on the expansion of a bioeconomy [1] that creates a socially and environmentally sustainable economy, reduces dependence on fossil resources, provides renewable raw materials and energy, creates jobs in rural areas, and improves national or regional competitiveness [2,3]. A dedicated bioeconomy strategy was adopted by the EU in 2012 with an update in 2018 [2,4]. Moreover, nine EU Member States have already specified their own bioeconomy strategy at national level and in six Member States a dedicated national bioeconomy strategy is under development; in the remaining Member States bioeconomy policies are incorporated into other strategies [5]. In the 2012 Bioeconomy Strategy of the EU the bioeconomy is defined as 'the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy' [2, p. 17]. The updated 2018 Bioeconomy Strategy extends the definition of the bioeconomy to 'all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles' [4, p. 4]. However, many competing definitions of the bioeconomy used by countries or stakeholders and limitations of available statistical data cause difficulties in measuring the bioeconomy and in assessing its role for national economies [1,6–8]. This has resulted in an important knowledge gap in the literature, which will become even more important as the bioeconomy is expected to expand in the future.

Quantitative measurement of the contribution of the bioeconomy to aggregate output, employment or environmental indicators either does not exist or is not internationally, temporally or methodologically consistent [1,8,9]. Empirical studies evaluate the contribution of the bioeconomy to a country's economy employing approaches ranging from local industry surveys (e.g. Ref. [10]) to complex partial or general equilibrium models (e.g. Ref. [11]). A widely used technique in economic analysis is the use of input-output models [7,12,13]. Input-output models, or extended (multiregional) models utilising data from input-output tables, have been implemented to determine the size of the bioeconomy as well as to assess economy-wide impacts of measures intended to boost the bioeconomy (see Refs. [9,14–25]). Because

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country-level studies usually provide incomparable results, Ronzon et al. have made an effort to harmonise the monitoring of turnover, value added and employment in the bioeconomy across EU Member States using sectoral statistics and expert estimates [6,26,27]. Nevertheless, empirical analysis mainly focuses on the assessment of the economic importance of the bioeconomy whereas social and environmental aspects are addressed only to a small extent [7].

Our study aims to contribute to the discussion on defining and measuring the bioeconomy. Geographically, it is applied to four Central European countries: Slovakia, Czech Republic, Poland, and Hungary. During the historical development the four countries established cooperation in a number of areas, and in 1991 they formed the Visegrad group (abbreviated V4) [28]. A process of implementing a sustainable bioeconomy in the Visegrad region was initiated in 2015 and in 2016 the countries started a governmental initiative for the bioeconomy, the BIOEAST Initiative (Central and Eastern European Initiative for Knowledge-based Agriculture, Aquaculture and Forestry in the Bioeconomy) [29–31]. Seven more countries have joined the Initiative (Bulgaria, Romania, Slovenia, Croatia, Estonia, Latvia, Lithuania) [32] and in 2020 the BIOEAST adopted a position paper confirming the commitment to support bio-based solutions in the macro region [33].

While policy cooperation in the field of the bioeconomy is quite well developed, empirical research and the knowledge base for the bioeconomy in Visegrad countries lag behind. There is only a limited number of studies that focus on evidencing and measuring the bioeconomy and its contribution to the total economy for the four countries in the Group. Bartokova [34] accessed only a specific part of the bioeconomy, the agricultural and food sector, in all four Visegrad countries. Loizou et al. [22] calculated output, employment and income multipliers and elasticities to assess bioeconomy sectors in Poland and Hajek et al. [35] analyzed the bioeconomy in the Czech Republic. The Ministry of Agriculture and Rural Development of the Slovak Republic [36] collected national data for revenues and employment in the Slovak bioeconomy. To our knowledge, there are no studies investigating environmental indicators of the bioeconomy in the Visegrad countries (although studies for other countries exist, e.g. for Ireland [23], for the Baltic States [21], or for Denmark and its trade partners [12]).

In this study the potential size of the bioeconomy in the Visegrad region is quantified in terms of economic and environmental indicators by applying a consistent input-output methodology based on official input-output tables. This means that bioeconomy indicators are computed from existing data that are commonly collected by statistical offices under the system of national accounts and hence, the approach allows for comparison among the four Visegrad countries; in addition, it could be used for any other country. Apart from traditional economic indicators (production, value added, employment), the study provides also evidence for environmental indicators represented by greenhouse gas (GHG) emissions. The incorporation of environmental indicators into a uniform monitoring system for the bioeconomy can be considered the main contribution of this study as environmental sustainability of economic systems gains on importance and the bioeconomy is expected to help the achievement of emission targets [37].

2. Material and methods

For the purpose of this study, the bioeconomy is specified as that part of the economy that serves to produce final bioeconomy products. Bioeconomy products are characterised as products entirely or partially based on biological resources. In statistics, namely the CPA classification of products, bioeconomy products are covered by divisions CPA 01 Products of agriculture, hunting and related services, 02 Products of forestry, logging and related services, 03 Fish and other fishing products, aquaculture products and support services to fishing, 10 Food products, 11 Beverages, 12 Tobacco products, 15 Leather and related products, 16 Wood and products of wood and cork (except furniture), articles of straw and plaiting materials, 17 Paper and paper products, 13 Textiles, 14 Wearing apparel, 20 Chemicals and chemical products, 21 Basic pharmaceutical products and pharmaceutical preparations, 22 Rubber and plastics products, 31 Furniture, 35 Electricity, gas, steam and air conditioning. This scope of the bioeconomy is analogical to Ronzon et al. [6,26,27], although their study uses a sector-based definition of the bioeconomy linked to the NACE classification of activities. Production of the abovementioned bioeconomy products includes several interdependent activities (adopted from Ref. [14]):

- bio-transformative activities: production and transformation of biological resources,
- forward linkages: upstream suppliers of bio-transformative activities,
- backward linkages: downstream users of the outputs of bio-transformative activities.

Interdependencies stem from flows of inputs exploited in final production that are themselves the output of intermediary production processes [17]. To capture activities carried out to produce final bioeconomy products and to quantify the performance of the bioeconomy in terms of output, value added, employment, and GHG emissions in Visegrad countries, an input-output analysis is used. The analysis was performed separately for each of the V4 countries and bioeconomy indicators for the Visegrad group as a whole have been obtained by adding up individual countries' results.

Following the input-output framework developed by Wassily Leontief in the 1930s [38], total production of a product is linked to final demand for all products produced in an economy:

$$\boldsymbol{y} = (I - A)^{-1} * \boldsymbol{f} \tag{1}$$

where $\boldsymbol{y}$ is a vector of total production by products, $\boldsymbol{f}$ is a vector of final demand by products, A is a matrix of input-output coefficients a_{ij} (where a_{ij} is the amount of product i required per unit of product j – Leontief technology is assumed in production), I is the identity matrix.

Value added created in the production of the various products is:

$$\boldsymbol{v} = \widehat{C} * \boldsymbol{y} \tag{2}$$

where $\boldsymbol{v}$ is a vector of value added by products, $\widehat{C}$ is a diagonal matrix of input-output coefficients for value added by products (the amount of value added per unit of product j).

Assuming proportional relations between production and related variables, employment and emissions associated with the production in an economy can be derived as follows:

$$\boldsymbol{e} = \widehat{H} * \boldsymbol{y} \tag{3}$$

where $\boldsymbol{e}$ is a vector of employment or emissions, respectively, by products, $\widehat{H}$ is a diagonal matrix of coefficients for employment or emissions, respectively, by products (employment per unit of product j or emissions per unit of product j).

If we let final demand in an economy to consist only of bioeconomy products, we can quantify the indicators of interest for the bioeconomy (production, value added, employment, emissions).

However, final demand for bioeconomy products cannot be obtained directly because some products can be either bio-based or fossil-based and statistics do not distinguish these two alternatives (for example, final demand for products of the CPA division 13 Textiles integrates textiles from natural and synthetic fibres). We, therefore, propose to adjust final demand for each product by the share of bio-based production in total production of the particular product. The derived final demands will be elements of the vector of final demand for bioeconomy products:

$$f_i^B = s_i * f_i \quad for\ all\ i \tag{4}$$

where f_i^B is final demand for product i attributed to the bioeconomy, s_i is the share of bio-based production in total production of product i, f_i is final demand for product i.

Shares of bio-based production in total production of the particular product can range from 0 if the product is fossil-based to 1 if the product is based entirely on biological resources. Similarly to Ronzon et al. [6, 27], we propose to set these shares to:

- $s_i = 1$ if i relates to products produced from biological resources and products based on these resources (further referred to as fully bioeconomy products). This group includes CPA 01 Products of agriculture, hunting and related services, 02 Products of forestry, logging and related services, 03 Fish and other fishing products, aquaculture products and support services to fishing, 10 Food products, 11 Beverages, 12 Tobacco products, 15 Leather and related products, 16 Wood and products of wood and cork (except furniture), articles of straw and plaiting materials, 17 Paper and paper products.
- $s_i = s_k$ (with $0 \leq s_k \leq 1$) if i relates to products that can be either bio-based or fossil-based (further referred to as partially bioeconomy products). This group includes: CPA 13 Textiles, 14 Wearing apparel, 20 Chemicals and chemical products, 21 Basic pharmaceutical products and pharmaceutical preparations, 22 Rubber and plastics products, 31 Furniture, 35 Electricity, gas, steam and air conditioning.
- $s_i = 0$ if i relates to fossil-based products not belonging to the bioeconomy (CPA divisions 05, 06, 07, 08, 09, 18, 19, 23, 24, 25, 26, 27, 28, 29, 30, 32, 33).
- $s_i = 0$ if i relates to services (CPA divisions 36–99).

A challenge is to obtain shares of bio-based production in total production of partially bioeconomy products (s_k). These shares are not known and they cannot be obtained from available statistical sources. Therefore, we consider three scenarios:

- scenario *Min* assumes that none of the partially bioeconomy products are bio-based, hence they do not belong to the bioeconomy and $s_k = 0$ for each k related to partially bioeconomy products,
- scenario *Max* assumes that all partially bioeconomy products are bio-based, hence they belong to the bioeconomy and $s_k = 1$ for each k related to partially bioeconomy products,
- scenario *Mid* assumes that partially bioeconomy products may be bio-based as well as fossil-based and only the bio-based fraction belongs to the bioeconomy. Shares of bio-based products in total production of the particular partially bioeconomy product are proxied as shares of bio-based inputs in all material inputs used to produce the product (in value terms). These shares can be calculated using a system of equations:

$$s_k = \sum_i (s_i * inp_{ik}) \Big/ \sum_i inp_{ik} \quad \text{for all } k \tag{5}$$

where inp_{ik} are deliveries of product i into the production of product k (intermediate domestic inputs and also imported inputs of product i into the production of product k). Here, the index k relates to partially bioeconomy products (CPA 13, 14, 20, 21, 22, 31, 35), and i relates solely to material inputs (CPA 01–35).

An overview of the scenarios can be found in Appendix A.

Production needed to meet final demand for bioeconomy products in each of the scenarios can be obtained using equation (1). By summing up all values in y, production of the whole bioeconomy is obtained. The remaining indicators of the bioeconomy (value added, employment, and emissions) can be calculated analogically using equations (2) and (3). Scenarios *Min* and *Max* are considered as bounds indicating the potential size of the bioeconomy. Scenario *Mid* strives to estimate the actual size of the bioeconomy.

2.1. Data

Our input-output analysis is based on product-by-product input-output tables, which are an integral part of the system of national accounts in EU countries (tables are available online from Statistical Offices of Slovakia, Czechia, Poland and Hungary). We have extended the input-output tables by employment and emissions statistics. As multiple sources of employment statistics exist, employment data were adapted from datasets methodologically consistent with the system of national accounts (Statistical Office of the Slovak Republic: 'Employment by industry A88', Czech Statistical Office: 'Total employment', Polish and Hungarian data retrieved from Eurostat 'National accounts employment data by industry up to NACE A64'). Eurostat database 'Air emissions accounts by NACE Rev. 2 activity' was the source for emission statistics. It should be noted that employment and emissions statistics are available for industries by the 2-digit NACE classification. We assume a perfect correspondence between NACE and CPA classification in input-output tables. If employment or emission statistics were aggregated for several NACE divisions, meaning their level of detail did not match the number of CPA divisions in input-output tables, employment was disaggregated using shares of the aggregated divisions in labour costs obtained from input-output tables, carbon dioxide emissions were disaggregated using shares in energy consumption (electricity and transport), methane emissions were disaggregated using shares in sewage and waste services, and nitrous oxide emissions were disaggregated using shares of the aggregated divisions in transport costs.

Data used in this study are for 2015. The input-output tables were given in basic prices in national currencies, so results have been converted to Euros. (Slovak input-output tables were given in thousand EUR, Czech in million CZK, Polish in thousand PLN, and Hungarian in million HUF. National currencies were converted to Euros using 2015 average exchange rates: 1 EUR = 27.283 CZK, 1 EUR = 4.1839 PLN, 1 EUR = 309.90 HUF.) Employment statistics refer to total employment in persons and emission statistics to tonnes of a pollutant.

3. Results

3.1. Basic indicators of V4 economies

Basic indicators of the economy for all four Visegrad countries are presented in Table 1. With a total production of EUR 186,830 mil., value added of EUR 71,446 mil., working population of 2.3 mil. people and one third of domestic production being exported (in 2015), the Slovak economy is a small and open economy. Its production is dominated by services (more than 50% of the value of total production) and industrial products (almost 45% of the value of total production). Primary commodities from agriculture, forestry and fishing contribute only 2.6% to the value of production and 3.2% to employment. They also contribute 6.3% to GHG emissions, with the production of agricultural products being the main source of nitrous oxide emissions (a share of 53% in total nitrous oxide emissions).

In Hungary, a working population of more than 4.3 mil. people produces an output of EUR 222,649 mil. and value added of EUR 94,413 mil. (as of 2015). Industrial products and services prevail in the structure of the Hungarian economy. Supported by a suitable landscape and climate, products of agriculture and hunting, products of forestry, fish and other fishing products build up more than 4% of total production value, of value added as well as of employment. The three product categories lead to 18% of total GHG emissions, thereof agricultural products are responsible for 90% of nitrous oxide emissions.

The Czech economy is dominated by services followed by manufactured goods. It shows a total production of EUR 389,775 mil. and value added of EUR 151,581 mil. in 2015. Total employment exceeds 5.1 mil. people. Primary production creates 2.4% of the output value and value added, and 3.2% of employment. Emissions linked to the production of agricultural, forestry and fish products reach 2% in total

Table 1
Indicators of the total economy, 2015.

Indicator	Slovakia	Czechia	Poland	Hungary	V4
Total production [mil. Eur, basic prices]	186,830	389,775	856,938	222,649	1,656,192
Value added [mil. Eur, basic prices]	71,446	151,581	381,550	94,413	698,990
Employment [th. of persons]	2,267	5,182	15,970	4,313	27,732
GHG emissions [th. tonnes in CO_2 eq.][a]	34,976	100,449	341,788	47,510	524,723
CO_2 emissions [th. tonnes][a]	28,806	82,942	275,842	36,523	424,113
CH_4 emissions [th. tonnes in CO_2 eq.][a]	4,342	12,864	47,189	6,791	71,186
N_2O emissions [th. tonnes in CO_2 eq.][a]	1,828	4,643	18,757	4,197	29,425

V4: countries of the Visegrad group (Slovakia, Czechia, Poland, Hungary).
[a] Greenhouse gases: CO_2 carbon dioxide + CH_4 methane + N_2O nitrous oxide; without emissions from households.
Source: national Statistical Offices and Eurostat.

carbon dioxide emissions, 27% in methane emissions and 73% in nitrous oxide emissions (8.5% in GHG emissions).

Poland is the largest country in the Visegrad group. In 2015, its production was worth EUR 856,938 mil., value added EUR 381,550 mil. and total employment included almost 16 mil. people. Commodities from agriculture, forestry and fishing contribute 2.5% to the value of the economy's output, 3.2% to value added, even 11.5% to total employment, 5% to carbon dioxide emissions and 13% to total GHG emissions.

3.2. *Current size of the bioeconomy (scenario Mid)*

The part of the economy that serves to meet final demand for bioeconomy products indicates the size of the bioeconomy in each country. An estimate of the current size of the bioeconomy in individual Visegrad countries is given by the scenario *Mid*. Table 2 shows the size of the bioeconomy in each country and the share of the bioeconomy in its total economy. For Slovakia and Czechia the contribution of the bioeconomy to the total economy varies around 9% for value added, production value and employment. The share of bioeconomy employment in total employment in Hungary is 9.95%, while the share of the bioeconomy in value added is 10.19% and in total production 12.29%. The highest shares are recorded for Poland, where the bioeconomy creates 11.91% of total value added, 15.58% of total production and 19.25% of total employment. Bioeconomy GHG emissions make up 11.99% of GHG emissions in Slovakia, 15.15% in Czechia, 21.69% in Poland and 24.63% in Hungary.

In the Visegrad region as a whole, the bioeconomy is expected to build up 13.06% of the value of economic output, 10.63% of total value added, 15.30% of total employment, and 20.06% of GHG emissions. In absolute terms, the value of bioeconomy production in the region achieves EUR 216,312 mil., bioeconomy value added EUR 74,283 mil., employment 4.2 mil. people, and GHG emissions almost 105.3 mil. tonnes in CO_2 equivalent (in 2015).

3.3. *Potential size of the bioeconomy (scenarios Min and Max)*

Fig. 1 visualises the potential size of the bioeconomy in each of the Visegrad countries determined by scenarios *Min* and *Max*. For comparison, the Figure also shows the current size of the bioeconomy (scenario *Mid*) and the size of the total economy in each country. The underlying values are provided in Appendix B. The potential contribution of the bioeconomy to the value of total production varies between 7.49% and 17.29% in Slovakia, 8.09% and 16.22% in Czechia, 13.52% and 22.68% in Poland, and 10.18% and 18.94% in Hungary. Hungary and Poland achieve higher potential shares of the bioeconomy because of the stronger position of primary biological resources in their total economic output. In all countries, bioeconomy production is determined by traditional sectors creating lower value added, hence, the share of the bioeconomy in total value added ranges from 6.94% (*Min* Czechia) to 18.02% (*Max* Poland). Except for Poland, shares of bioeconomy employment in total employment are similar to shares of value added. Due to high employment numbers in Polish agriculture, the share of the bioeconomy in total employment is estimated between 17.39% and 24.35%.

The contribution of fully bioeconomy production to GHG emissions ranges from 9.54% (*Min* Slovakia) to 20.64% (*Min* Hungary). Among greenhouse gases, the share of carbon dioxide from the bioeconomy is between 4.02% (*Min* Slovakia) and 13.33% (*Min* Poland). With a share above 60% in Slovakia and Czechia and above 75% in Poland and Hungary, the production of fully bioeconomy products significantly contributes to nitrous oxide emissions (as these originate mainly from the production of agricultural goods). If the production of partially bioeconomy products is completely attributed to the bioeconomy, its share in GHG emissions increases up to 47.10% (*Max* Czechia). Although our approach indicates the environmental footprint of the bioeconomy, it should be noted that GHG emissions may be overestimated as the approach does not account for different environmental impacts of fossil-based and bio-based technologies that might be used in

Table 2
Indicators of the bioeconomy and share of the bioeconomy in the country's total economy (scenario *Mid*), 2015.

Bioeconomy indicator	Slovakia	Czechia	Poland	Hungary	V4
Total production [mil. Eur, basic prices]	18,063 (9.67%)	37,362 (9.59%)	133,524 (15.58%)	27,363 (12.29%)	216,312 (13.06%)
Value added [mil. Eur, basic prices]	6,718 (9.40%)	12,485 (8.24%)	45,455 (11.91%)	9,625 (10.19%)	74,283 (10.63%)
Employment [th. of persons]	224 (9.86%)	515 (9.94%)	3,074 (19.25%)	429 (9.95%)	4,242 (15.30%)
GHG emissions [th. tonnes in CO_2 eq.][a]	4,195 (11.99%)	15,220 (15.15%)	74,142 (21.69%)	11,701 (24.63%)	105,258 (20.06%)
CO_2 emissions [th. tonnes][a]	1,907 (6.62%)	8,747 (10.55%)	43,588 (15.80%)	5,936 (16.25%)	60,178 (14.19%)
CH_4 emissions [th. tonnes in CO_2 eq.][a]	1,128 (25.99%)	3,421 (26.59%)	15,918 (33.73%)	2,549 (37.54%)	23,016 (32.33%)
N_2O emissions [th. tonnes in CO_2 eq.][a]	1,159 (63.42%)	3,052 (65.73%)	14,637 (78.04%)	3,216 (76.63%)	22,064 (74.98%)

V4: countries of the Visegrad group (Slovakia, Czechia, Poland, Hungary).
[a] Greenhouse gases: CO_2 carbon dioxide + CH_4 methane + N_2O nitrous oxide; without emissions from households.
Source: own calculations based on data from national Statistical Offices and Eurostat.

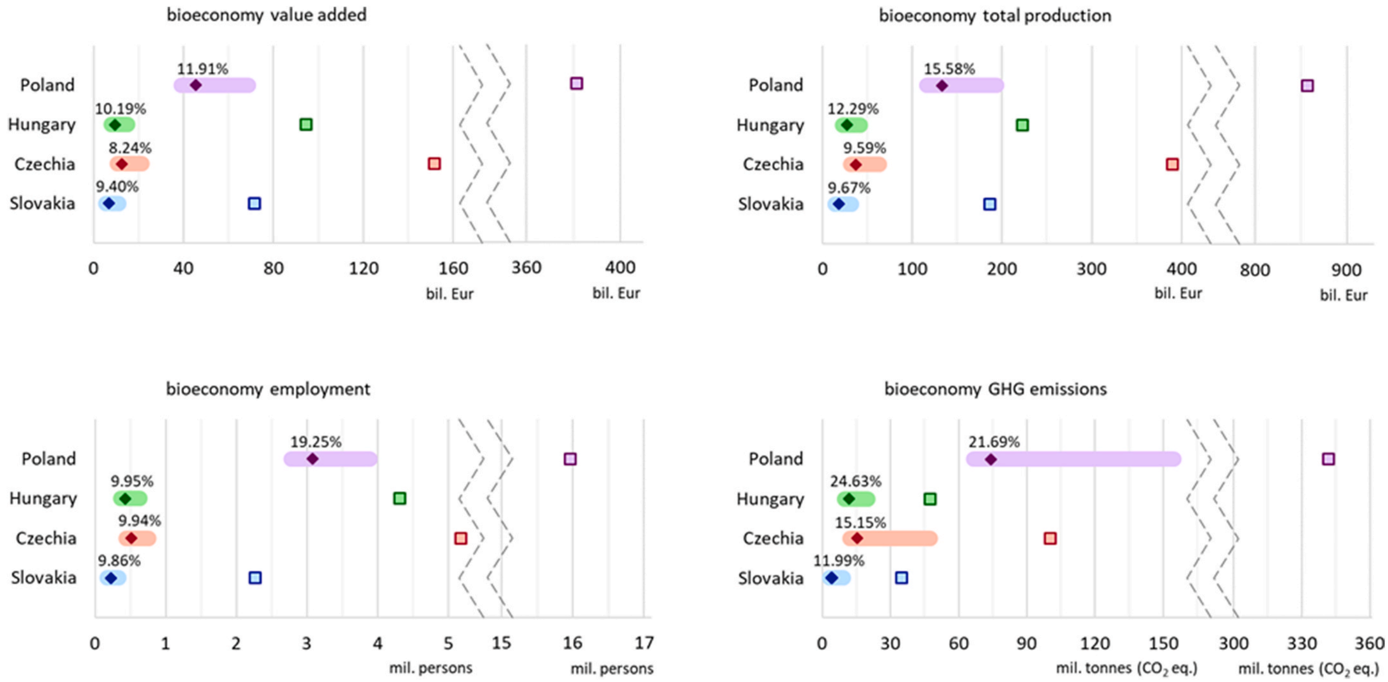

Fig. 1. Size of the bioeconomy in Visegrad countries, 2015.
Notes: ▬ - bioeconomy indicator (interval estimate) based on scenarios *Min* and *Max*.
◆ - bioeconomy indicator (point estimate) based on scenario *Mid* with percentage share of the bioeconomy in total economy.
◻ - total economy. Data source: own calculations based on data from national Statistical Offices and Eurostat.

Table 3
Comparison of bioeconomy value added and its share in the country's total economy determined by different studies, 2015.

Bioeconomy indicator	Slovakia	Czechia	Poland	Hungary	V4
1) This study					
Value added [mil. Eur]	6,718 (9.40%)	12,485 (8.24%)	45,455 (11.91%)	9,625 (10.19%)	74,283 (10.63%)
2) Ronzon et al.					
Value added [mil. Eur]	3,805	8,485	27,636	8,040	47,965
3) Cingiz et al.					
Value added [mil. Eur]	7,743 (10.90%)	14,119 (9.32%)	52,499 (13.80%)	10,787 (11.60%)	85,148 (12.23%)

V4: countries of the Visegrad group (Slovakia, Czechia, Poland, Hungary).
Note: For the study by Ronzon et al. shares of bioeconomy value added in the total economy could not be calculated because data for the whole economy are not available in the respective database (DataM).
Source: 1) own calculations, 2) Ronzon et al. [6,27] and the DataM database, 3) Cingiz et al. [16].

the production of partially bioeconomy products. The linear input-output model assumes fixed technology coefficients and constant returns to scale and as a result, bioeconomy indicators are proportionally related to production. If more detailed data were available, GHG emitted in the production of bio-based products could be determined more precisely.

For the whole Visegrad region, the bioeconomy's share in the total economy is estimated to range from 11.11% to 20.05% for the value of economic output, from 8.97% to 16.61% for value added, from 13.54% to 20.24% for employment and from 17.56% to 44.08% for GHG emissions. The contribution of the bioeconomy to the selected indicators is higher for larger countries, Poland and Hungary. An exception is the share of bioeconomy employment in Hungary, which is comparable to Slovakia and Czechia (with a higher share only in Poland). This does not mean that Poland or Hungary prefer bio-based production to fossil-based production for commodities where both production methods are possible (partially bioeconomy products), it rather indicates an important position of agricultural and food products in the structure of their economy and their bioeconomy.

4. Discussion

By applying the input-output analysis to Slovak, Czech, Polish and Hungarian data, we estimated the size of the bioeconomy and determined the share of the bioeconomy in the Visegrad countries' economies. The contribution of the bioeconomy to the total economy varies among individual countries, with Poland achieving the highest shares of the bioeconomy in terms of socio-economic indicators and Slovakia achieving the lowest share of the bioeconomy in GHG emissions (see Table 2). Diversity in the contribution of the bioeconomy to the total economy was also found for other countries. Heijman and Schepman [19] estimated that the bioeconomy in the Netherlands accounted only for 6.6% of total Dutch value added in 2015, while Liobikiene and Brizga [21] concluded that in the Baltic states the bioeconomy contributed 21%, 26% and 33% to the gross value added in Estonia, Latvia and Lithuania, correspondingly. Different shares of the bioeconomy in the total economy are caused on the one hand by different structure of the countries' economies, on the other hand by different input data and methodologies used to quantify bioeconomy indicators (including different scope of the bioeconomy).

Apart from our study, there are two more studies enabling a cross-country comparison of some bioeconomy indicators in the Visegrad region. Ronzon et al. [6,26,27] developed a methodology for three main socio-economic indicators and applied it to EU Member States. Their results show that turnover of the bioeconomy in the Visegrad countries was EUR 188,419 mil., value added was EUR 47,965 mil., and the bioeconomy employed 3.55 mil. people in 2015, which equalled 12.80% of total employment (DataM database, 2021). The authors used a sector-based definition of the bioeconomy and the indicators are based on specific sectoral statistics complemented by expert estimates. Cingiz et al. [16] calculated bioeconomy value added for all EU Members, and they reported value added of the bioeconomy in Visegrad countries of EUR 85,148 mil. They also used a sector-based definition of the bioeconomy although the range of sectors included is not identical to the former study and their data came from sector-by-sector input-output tables. Results for value added per country, which is and indicator analyzed in both studies, are summarized in Table 3 and compared to the results from this study. Our estimates for the current size of the bioeconomy in Visegrad countries are higher than bioeconomy indicators compiled by Ronzon et al. although the scope of the bioeconomy is analogical. Compared to the second study our estimates are lower although Cingiz et al. also used an input-output model and moreover they amended the calculation for possible double counting when the bioeconomy is defined such that it includes forward and backward linkages in production. In contrast to the previous studies, our study extends bioeconomy monitoring by environmental indicators.

When assessing the bioeconomy, a common problem in empirical analysis is the availability of data for products that can be both bio-based and fossil-based as statistics do not provide the required level of detail and bio-based products are not disaggregated from fossil-based products in the respective classification (the same is true for economic sectors, no distinction between bio-based and fossil-based sectors takes place in statistics). A possible solution is the application of bio-based shares to aggregated data. However, just as there is a variety of bioeconomy definitions and methodological frameworks for the bioeconomy in the literature, there are also several approaches to determining bio-based shares. The JRC and the nova-Institute interviewed a panel of experts who estimated bio-based content for a list of products and then Ronzon et al. [6,27] calculated bio-based shares of each economic sector as the relative value of bio-based products produced by a sector in the total value generated by the sector. Bauen et al. [14] utilised firm level data from the Trends Central Resource (TCR) database for the United Kingdom to attribute firms to the bioeconomy and to get the share of each sector that will be considered part of the bioeconomy. For the purpose of this study, we inferred bio-based shares of partially bioeconomy products from the value of bio-based material inputs in all material inputs (domestically produced and imported) that are used to produce the respective product. Bio-based shares can be obtained easily from each country's input-output tables, do not require expert estimates, but they do not account for possible differences in bio-based shares of domestic and imported material inputs.

5. Conclusion

The bioeconomy is expected to support a more sustainable economy based on renewable resources [27]. Thus, monitoring the bioeconomy is important from a policy perspective [1,39,40]. The input-output methodology described in this study can serve as the basis for a monitoring tool. For the four Visegrad countries, the applied model quantifies bioeconomy output, value added, employment, and GHG emissions (the list of indicators can be extended in the future), and it provides policy makers with information on the current and also potential size of the bioeconomy. This allows to formulate feasible objectives in national bioeconomy strategies of the countries and facilitates cooperation at international level (e. g. the BIOEAST initiative [41]). Encouraging bio-based production in textiles, wearing apparel, chemical products, pharmaceutical products, plastics products, furniture, and electricity (partially bioeconomy products), where substitution of fossil-based by bio-based resources may take place, stimulates the transition towards a bioeconomy. However, the application of new biotechnologies may change the characteristics of the production process, so for modelling the transition towards a bioeconomy in partially bioeconomy sectors further research is needed to extend the methodological framework. More intensive use of biological resources in production usually means a growing bioeconomy, on the other hand, it is connected to concerns about biomass availability and to environmental concerns like pressure on land or ambiguous effects on GHG emissions [13,42]. Because there is a trade-off between socio-economic and environmental objectives and markets are likely to focus on socio-economic effects [9,13], policies should consider both the socio-economic and environmental dimension of a sustainable bioeconomy. A regular ex-post assessment of the bioeconomy is recommended to reveal the progress in the development of the bioeconomy and in the achievement of policy targets.

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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Appendices.

Appendix A. Scenarios and shares of bio-based production in total production of products

	Scenario Min	Scenario Mid	Scenario Max
Goods (CPA 01–35)			
- fully bioeconomy products (CPA 01, 02, 03, 10, 11, 12, 15, 16, 17)	$s_i = 1$	$s_i = 1$	$s_i = 1$
- partially bioeconomy products (CPA 13, 14, 20, 21, 22, 31, 35)	$s_i = 0$	$s_i = s_k$	$s_i = 1$
- not bioeconomy products (CPA 05–09, 18–19, 23–30, 32–33)	$s_i = 0$	$s_i = 0$	$s_i = 0$
Services (CPA 36–99)	$s_i = 0$	$s_i = 0$	$s_i = 0$

where i, k only relate to products within the respective group and $k = i$.

Shares for partially bioeconomy products (s_k) in scenario *Mid* obtained using equations (5) for each country:

Shares s_k for CPA product categories	Slovakia	Czechia	Poland	Hungary
CPA 13 – Textiles	0.388	0.318	0.198	0.226*
CPA 14 – Wearing apparel	0.366	0.289	0.204	
CPA 20 – Chemicals and chem. products	0.239	0.181	0.124	0.257
CPA 21 – Basic pharmaceutical products	0.376	0.349	0.274	0.281
CPA 22 – Rubber and plastics	0.227	0.188	0.158	0.229
CPA 31 – Furniture	0.736	0.484	0.561	0.315*
CPA 35 – Electricity, gas, steam	0.047	0.052	0.043	0.128

Source: own calculations based on data from national Statistical Offices.

*Hungarian input-output tables provide aggregated data for categories CPA 13–15 and also CPA 31–32. Therefore, the shares also relate to aggregated categories, $s_{CPA13-15} = 0.226$, $s_{CPA31-32} = 0.315$.

Appendix B. Bioeconomy indicators for Visegrad countries, 2015

Bioeconomy indicator	Scenario			Share in total economy		
	Min	Mid	Max	Min	Mid	Max
Slovakia						
total production [mil. Eur, basic prices]	14,002	18,063	32,298	7.49%	9.67%	17.29%
value added [mil. Eur, basic prices]	5,325	6,718	11,040	7.45%	9.40%	15.45%
employment [th. of persons]	173	224	331	7.65%	9.86%	14.62%
GHG emissions [th. tonnes in CO_2 eq.]*	3,337	4,195	9,344	9.54%	11.99%	26.71%
CO_2 emissions [th. tonnes]*	1,157	1,907	6,412	4.02%	6.62%	22.26%
CH_4 emissions [th. tonnes in CO_2 eq.]*	1,071	1,128	1,599	24.66%	25.99%	36.83%
N_2O emissions [th. tonnes in CO_2 eq.]*	1,109	1,159	1,332	60.66%	63.42%	72.87%
Czechia						
total production [mil. Eur, basic prices]	31,541	37,362	63,239	8.09%	9.59%	16.22%
value added [mil. Eur, basic prices]	10,524	12,485	21,371	6.94%	8.24%	14.10%
employment [th. of persons]	443	515	759	8.55%	9.94%	14.64%
GHG emissions [th. tonnes in CO_2 eq.]*	12,323	15,220	47,313	12.27%	15.15%	47.10%
CO_2 emissions [th. tonnes]*	6,059	8,747	39,199	7.31%	10.55%	47.26%
CH_4 emissions [th. tonnes in CO_2 eq.]*	3,299	3,421	4,602	25.64%	26.59%	35.77%
N_2O emissions [th. tonnes in CO_2 eq.]*	2,965	3,052	3,512	63.86%	65.73%	75.64%
Poland						
total production [mil. Eur, basic prices]	115,859	133,524	194,333	13.52%	15.58%	22.68%
value added [mil. Eur, basic prices]	38,930	45,455	68,742	10.20%	11.91%	18.02%
employment [th. of persons]	2,778	3,074	3,888	17.39%	19.25%	24.35%
GHG emissions [th. tonnes in CO_2 eq.]*	66,681	74,142	154,692	19.51%	21.69%	45.26%
CO_2 emissions [th. tonnes]*	36,777	43,588	118,457	13.33%	15.80%	42.94%
CH_4 emissions [th. tonnes in CO_2 eq.]*	15,411	15,918	20,631	32.66%	33.73%	43.72%
N_2O emissions [th. tonnes in CO_2 eq.]*	14,493	14,637	15,604	77.27%	78.04%	83.19%
Hungary						
total production [mil. Eur, basic prices]	22,656	27,363	42,181	10.18%	12.29%	18.94%
value added [mil. Eur, basic prices]	7,932	9,625	14,984	8.40%	10.19%	15.87%
employment [th. of persons]	362	429	634	8.39%	9.95%	14.70%
GHG emissions [th. tonnes in CO_2 eq.]*	9,805	11,701	19,973	20.64%	24.63%	42.04%
CO_2 emissions [th. tonnes]*	4,173	5,936	13,716	11.43%	16.25%	37.55%

(*continued on next page*)

(*continued*)

Bioeconomy indicator	Scenario			Share in total economy		
	Min	Mid	Max	Min	Mid	Max
CH_4 emissions [th. tonnes in CO_2 eq.]*	2,462	2,549	2,892	36.25%	37.54%	42.59%
N_2O emissions [th. tonnes in CO_2 eq.]*	3,171	3,216	3,364	75.55%	76.63%	80.17%

Source: own calculations based on data from national Statistical Offices and Eurostat.

*Greenhouse gases: CO_2 carbon dioxide + CH_4 methane + N_2O nitrous oxide; without emissions from households.

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